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INTEGRATING OCCUPATIONAL HEALTH AND SAFETY IN FACILITY PLANNING AND LAYOUT DESIGN

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Cette thèse intitulée:

INTEGRATING OCCUPATIONAL HEALTH AND SAFETY IN FACILITY PLANNING AND LAYOUT DESIGN

présentée par : MOATARI KAZEROUNI Afrooz

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DEDICATION

To engineering,

for evolving lives.

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I hope this work makes you proud.

RÉSUMÉ

L'aménagement de l'usine est un atout pour les organisations. Il considère la conception, l'aménagement, l'emplacement et l'hébergement des personnes, des machines et des activités d'un système ou d'une entreprise dans son environnement physique. Les décisions appropriées sur l'aménagement de l'usine, concernant l'allocation spatiale des départements et des machines ainsi que les connexions nécessaires entre eux, ont pour but d'organiser la production le plus efficacement possible et d'améliorer la sécurité. Une usine bien conçue doit assurer qu'un espace suffisant est affecté à l'entretien et à l'exploitation que les mouvements non nécessaires sont évités et l'usine doit assurer que mouvement de la machine est bien considérée.

Dans les deux dernières décennies, les chercheurs ont développé des modèles de simulation et de programmation mathématique pour estimer différentes mesures de performance d'un système de production. Alors que la préoccupation principale de ces modèles est de réduire le coût de manutention de matériel, la configuration d'une usine joue un rôle majeur dans la sécurité et la productivité des opérations. En dépit de sa grande importance, le point de vue de la santé et de la sécurité au travail (SST) a généralement été négligé dans la planification des installations. Il n'y a pas beaucoup de lignes directrices existent pour aider les industries à trouver des solutions raisonnables aux problèmes soulevés de sécurité dans la conception de l'aménagement d'une l'usine. En intégrant les aspects essentielles en matière de SST dans la phase initiale de conception d'un aménagement d'une usine, l'organisation évitera des conditions de travail dangereuses et des pertes financières résultant d'accidents sur le lieu de travail.

L'objectif principal de cette thèse est de proposer une méthode pour l'intégration de la SST dans les décisions d'aménagement d'usine. Trois questions de recherche sont étudiées: (i) quels sont les facteurs de SST qui doivent être pris en compte lors de l'aménagement d'une usine, (ii) comment les facteurs de SST peuvent être mesurés quantitativement, et (iii) comment intégrer les facteurs SST dans les outils d'aménagement d'usine.

Cette recherche propose un modèle pour les planificateurs de l'usine en ce qui concerne les aspects en matière de SST dans l'aménagement de l'usine. Une directive de SST est introduite pour être utilisée lors de l'aménagement de l'usine pour identifier les problèmes de sécurité. Un outil d'estimation du risque amélioré est proposé. Il peut être utilisé pour quantifier la valeur d'un risque associé aux problèmes de sécurité qui sont identifiés à l'aide les directives de SST. Cet

outil est intégré dans l’outil d’aménagement de l'usine et une étude de cas est présentée pour démontrer l’efficacité de la méthodologie.

En utilisant l’outil proposé les différents facteurs de la SST seront considérés lors de l'aménagement d’une usine. Pour cette matière, les facteurs de sécurité sont examinés et sont inclus, tout en optimisant d'autres facteurs tels que les limitations de coût et de l’espace, ou la proximité des départements, qui ont souvent été les principaux objectifs de l'aménagement d’une usine.

ABSTRACT

Facility layout planning is becoming an asset for the organizations. It considers the design, layout, location and accommodation of people, machines and activities of a system or enterprise within a physical environment. Appropriate decisions on facility layout, concerning the spatial allocation of departments and machines as well as the required connections among them, can organize the production more efficiently and increase safety. A well-designed facility can ensure that adequate space is assigned for maintenance and operation that unnecessary movements are avoided, and the range of machine movement is considered.

In the past two decades, researchers have developed simulation and mathematical programming models to estimate the performance measures of a production system. While the main concern with these models is to reduce the cost of material handling, the layout of a facility plays a major role in the safety and productivity of operations. Despite its immense importance, Occupational Health and Safety (OHS) perspective has been overlooked in facility layout planning. Little guidance exists to assist industries in finding reasonable solutions to the issues raised from safety in the layout design. By incorporating vital OHS aspects into the initial design phase of a facility layout, the organization will avoid unsafe work conditions and financial losses resulting from accidents.

The main purpose of this dissertation is to propose a method of integrating OHS in the facility layout planning model. Three research questions are investigated: (i) what are the OHS factors that need to be considered in facility planning, (ii) how OHS factors can be measured quantitatively, and (iii) how OHS factors can be integrated in the facility planning models.

This research proposes a tool for facility planners in regards to the OHS aspects in layout design. An OHS guideline is introduced to be used by facility planners for identifying the safety issues in designing a layout. An improved risk estimation tool is proposed. It can be used to quantify the risk value associated with the safety issues which are identified via the OHS guideline. This tool is integrated into the facility planning model and a case study is presented to illustrate the methodology.

By using the proposed integrated facility planning tool, different OHS factors would be considered while designing the layout for a facility. For this matter, safety factors are considered

and are included while optimising other factors such as cost and space limitations, or the closeness of departments, which have usually been the main objectives in layout design.

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
ANN	Artificial Neural Network
CSST	Occupational Health and Safety Commission
EIA	Environmental Impact Assessments
ERA	Environmental Risk Assessment
FIOH	Finnish Institute of Occupational Health
FLP	Facility Layout Problem
ES	Expert System
HAV	Hand-Arm Vibration
GA	Genetic Algorithm
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organisation for Standardisation
LIP	Linear Integer Programming Problem
MIP	Mixed Integer Programming Problem
MSDs	Muscular Skeletal Disorders
NIOSH	National Institute for Occupational Safety and Health
NORA	National Occupational Research Agenda
OHS	Occupational Health and Safety
PPE	Personal Protective Equipment
QAP	Quadratic Assignment Problem
QEC	Quick Exposure Check
QSP	Quadratic Set-Covering Problem
SA	Simulated Annealing

SLP	Systematic Layout Planning
SST	Santé et de la Sécurité au Travail
TS	Tabu-search
WHMIS	Workplace Hazardous Materials Information System

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INTRODUCTION

Industrial and manufacturing companies are facing many problems in today’s competitive environment (Gopalakrishnan et al., 2004). Among the biggest challenges facing manufacturers are cost of doing business, taking in skilled workers, healthcare and safety, accident-free environments, healthcare costs, quality and customer expectations, and culture changes. To overcome these challenges, companies need to focus on possible improvements, productivity, quality, resource, and space (Wang, 2010). Selecting a good layout, which is defined as the physical arrangement of machines, personnel, raw materials and finished goods (Roslin et al., 2008), is a critical decision in facilities planning, since the layout selection will serve to establish the physical relationships between activities. A well-designed facility can minimize the amount of land occupied and the movements in its processes while maintaining easy access to the space around individual units and providing safe zones among them. It not only reduces investment costs but also avoids or minimizes safety and maintenance problems (Penteado and Ciric, 1996).

Efficient facility layout is essential in any industrial sector in order to improve quality, productivity, and competitiveness. The objective of facility layout is to provide the best arrangement of process equipment in a plant. Therefore, the criteria for evaluating a good layout necessarily relates to workers, materials, machines and their interactions.

A manufacturing company is considered as a complex human-machine-environment-organization system (Shikdar et al., 2002). In other words, a company contains a large number of systems which interact to achieve its business objectives (Waeyenbergh and Pintelon, 2002). Occupational Health and Safety (OHS) contributes heavily to the achievement of these objectives. Proper OHS considerations ensure regulatory compliance, improves productivity and wellbeing of personnel, keep the cost down by avoiding stoppage time following accidents and investigations as well as avoiding fines and lawsuits; OHS contributes positively to the overall performance of a company (Jallon et al., 2011a, b).

OHS is a cross-disciplinary area concerned with protecting safety, health and welfare of people engaged in a work environment. There are basic ways to improve the safety in a company; safe layout design which aims to eliminate the hazards, engineering solutions, safe working methods, as well as safety trainings. As such, considering the safety of working environment at a company, as early as in the design stage of the facility layout, can be a preventive solution.

As a result, many laws, regulations, and risk analysis techniques are presented according to industry needs. Occupational safety risk estimation is the core of any safety practices in any industry (Pinto, 2014). Risk estimation is the process of systematically guiding risk reduction and management activities based on collecting and evaluating data on severity of a harmful event and probability of occurrence of that harm. It is a complex process that entails consideration of many parameters, which are difficult to quantify.

Hence, efforts to provide work safety in companies are not only important for the health of workers but also inevitable managerial activities for economic and financial performance, productivity of the facility and the quality and continuity of production (Dağdeviren and Yüksel, 2008). Additionally, it is not only the manufacturing companies that require work safety cautions; service industries are no exception.

The main objective of this research is to reduce accidents and occupational injuries of workers. The scope of this dissertation is on evaluating safety aspects in planning new facilities or the redesign process. The originality of this work is within considering safety at the same level as more traditional factors such as cost, productivity, quality products, space, or innovative improvements in facility layout planning models.

This PhD research investigated how the existing facility planning models and risk estimation tools can be modified and integrated in order to provide a more robust method that meet productivity and safety requirements. Risk estimation tools as well as the facility layout planning models are thoroughly studied. An improved risk estimation tool is developed based on the characteristics, strengths, and weaknesses of existing risk estimation tools. This tool is used to integrate OHS into a new facility planning model. A facility layout design approach is proposed which considers transportation cost as well as safety concerns. By this means, the OHS aspects are reflected prior to the construction of a facility. Moreover, as another outcome of this research, a comprehensive list of OHS criteria is produced. It consists of OHS factors for facility managers to use as a guideline at early stages of a facility design or redesign. This OHS guideline was presented as a peer reviewed conference paper (Moatari-Kazerouni et al., 2012).

The rest of the dissertation is structured as follows: Chapter 1 reviews the literature concerning facility layout planning as well as the OHS and risk estimation; Chapter 2 describes the research objectives, approach and the methodology employed; Chapters 3 presents the OHS guideline for facility planning; Chapter 4 proposes an improved risk estimation tool; Chapter 5 proposes a facility layout planning model which considers OHS aspects; Chapter 6 validates the use of the methodology through a case study. The works presented in Chapters 3-6 report the contributions of this dissertation as the three articles published in the International Journal of Production Research as well as the peer reviewed conference paper appeared in the proceeding of the 4th International Conference on Information Systems, Logistics and Supply Chain (2012). Chapter 7 discusses the findings. The document will then conclude with a synthesis, the limitations of this work, and future perspectives.

CHAPTER 1 LITERATURE REVIEW

1.1 Introduction

One of the major factors determining the economic success of manufacturing companies is the ability to maintain a competitive advantage in an increasingly competitive global marketplace (Hallbeck et al., 2010). Companies are under pressure to rationalize production systems by targeting factors such as the layout design, production capacity, and cost efficiency. Some of the common features of these industries are improper layout design, ill-structured jobs, mismatch between worker abilities and job demands, adverse environment, and poor human-machine system design (Shikdar and Sawaqed, 2003). These features create problems of occupational accidents and injuries amongst workers. Therefore, the manufacturing industry is one of the most dangerous branches in light of the frequency of occupational accidents (Silvestri et al., 2012).

It is estimated that at least 250 million occupational accidents occur every year worldwide. 335,000 of these accidents are fatal (ILO, 2012). This number can be reduced if facility planners improve the working environment safety by integrating safety considerations into the layout design process.

One of the most influential factors affecting the efficiency of a facility is its layout. The interactions between each pair of departments (i.e., workstations, machines, etc.) must be taken into account in order to obtain an efficient layout (Abdinnour-Helm and Hadley, 2000). A measure for efficiency can be based on the total cost of transporting the materials between different departments. In practice many more factors need to be considered other than minimizing the movement costs (Heragu, 2006). An important factor is providing a safe environment for personnel. Employees' health and safety is an area that has become a source of motivation behind different facility planning studies to accomplish goals in terms of material handling, personnel and equipment utilization (Tompkins, 2010).

Unlimited number of hazards can be found in almost any facility. Giving adequate consideration to OHS and to eliminate or minimize possible hazardous conditions within the work environment during layout design of a facility is essential.

The following sections give a review of different approaches to the facility planning and layout design as well as to the risk estimation tools. Previous studies in exploring facility planning research, facility layout problem, and layout design models are presented. OHS concept is discussed through the literature review. Besides, different risk estimation methods and tools are mentioned. A detailed examination of every layout design approaches and risk estimation tool is not provided here but the key references are included. Previous approaches for including safety concerns in facility design are also described.

1.2 Facility Layout Planning and Design

Facility planning has taken a whole new meaning in the past decades. It was primarily considered as a science, whereas in today's competitive global marketplace, facility planning is a strategy (Tompkins, 2010). It includes facility location and layout design. Facility location refers to determining how the location of an activity supports the accomplishment of its intended objective. Facility layout design includes: structural design, layout design, and material handling system design. In particular, facility layout design is the field of selecting the most effective arrangement of physical workstations that allows the greatest efficiency in the allocation of resources needed to manufacture a product or perform a service (Russell and Taylor, 2000).

1.2.1 Facility Layout Problem Approaches

Determining the physical organization of a system is defined as facility layout problem (FLP). According to Shouman et al. (2001), the facility layout problem considers the assignment of facilities to locations so that the quantitative or qualitative objective of the problem is minimized or maximized. Koopmans and Beckmann (1957) were among the firsts to consider FLP and outlined its objective to configure departments for minimizing the cost of transporting materials between them. Therefore, the quantitative objective of the FLP is addressed as minimizing the material handling cost, while the qualitative objective is to maximize the subjective closeness rating by considering vital factors such as safety, flexibility, noise, etc. (Francis et al., 1974; Malakooti and Tsurushima, 1989).

A FLP is an unstructured decision problem. One of the real difficulties in developing and using models for layout design is the natural vagueness associated with the inputs to the FLP models (Deb and Bhattacharyya, 2003). However, it is one of the best studied problems in the field of combinatorial optimization and different approaches have been developed to tackle this problem. In the study by Kusiak and Heragu (1987), various formulations of the facility layout problem and the algorithms for solving this problem are presented. Twelve heuristic algorithms are compared on the basis of their performance with respect to eight test problems commonly used in the literature. Emerging trends in the facility layout problem are presented by Meller and Gau (1996), including new methodologies, objectives, algorithms, and extensions to the well-studied combinatorial optimization problem. The facility layout problem is surveyed by Shouman et al. (2001) too. Different conventional algorithms and intelligent techniques for solving FLP are presented, while general remarks and tendencies are reported. Singh and Sharma (2006) presented the current and future trends of research on facility layout problems based on previous research including formulations, solution methodologies and development of various software packages. A literature analysis is provided by Drira et al. (2007) and suggested a general framework to analyse the existing research using criteria such as: the manufacturing system features, static/dynamic considerations, continual/discrete representation, problem formulation, and resolution approach. Levary and Kalchik (1985) summarized the main characteristics of the most used solution procedures for the facility layout problem. The characteristics include the inputs, limitations, type of output obtained, and other general characteristics.

The FLP approaches can be classified into two categories of FLP formulations and solution algorithms, which are outlined in Figure 1-1.

Several algorithms and techniques are proposed for facility layout problems. Based on these algorithms, different models for the layout design are proposed. Table 1.1 shows a list of facility planning models for each of the aforementioned approaches. The first two columns of the table state these approaches. The third and fourth columns give examples of literature articles that have introduced FLP models. The objective and input is reviewed for each of the introduced models; e.g., closeness, flow cost, material handling cost, throughput rate, degrees of flexibility, etc.). Following section elaborates on different objectives of FLP models.

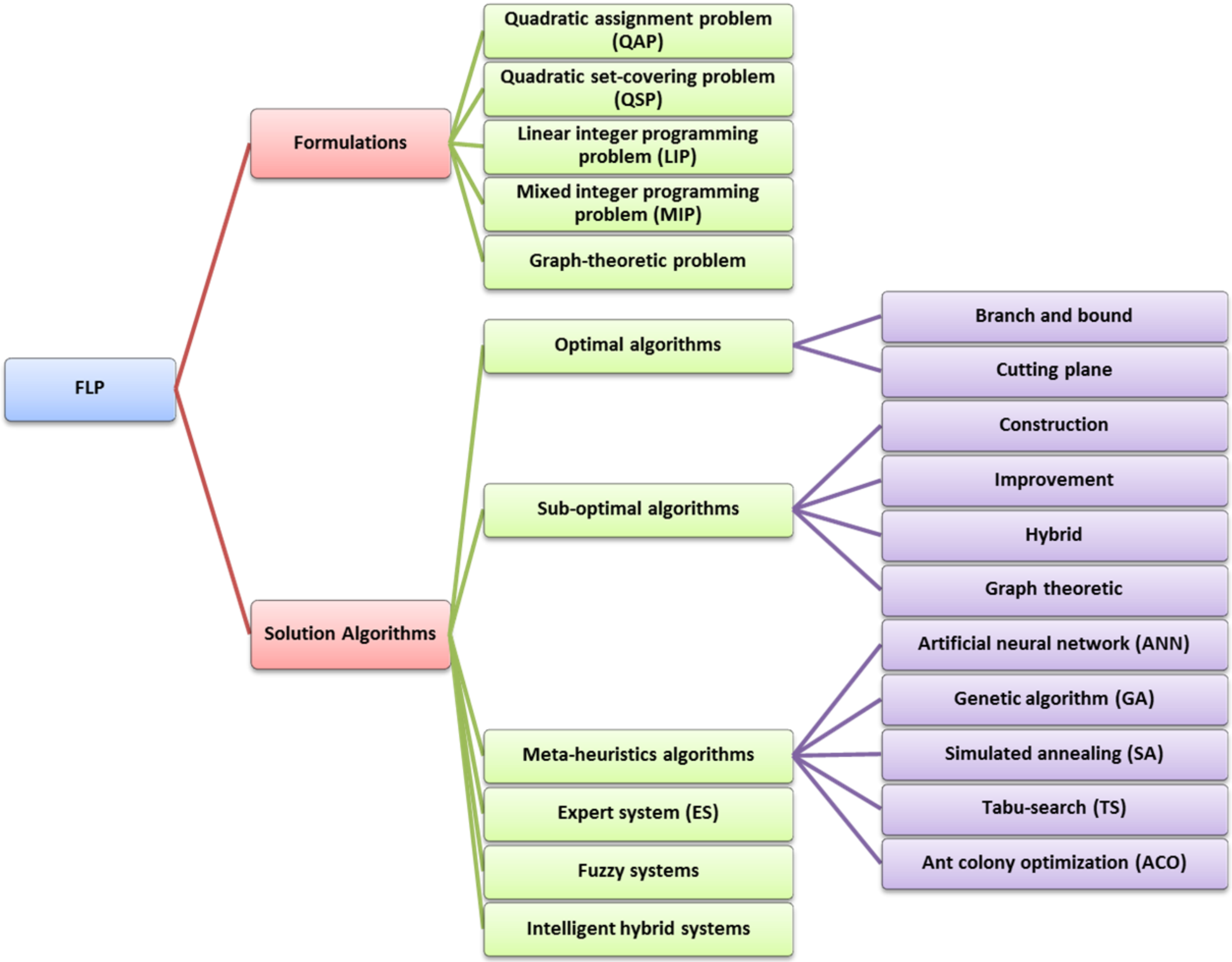

Figure 1-1: FLP approaches

Table 1.1: FLP solution algorithms and models

Approach		Reference	Model	Objective Input
Optimal algorithms	Branch and bound	(Tcha and Lee, 1984)		Total distribution costs, including fixed costs
		(Gavett and Plyter, 1966)		Distance Traffic intensity
		(Akinc and Khumawala, 1977)		Handling cost
		(Ro and Tcha, 1984)		Total cost
	Cutting plane	(Bazaraa and Sherali, 1982)		Interactive cost of simultaneously locating facilities at sites
		(Anjos and Vannelli, 2008)		Total cost
Sub-optimal algorithms	Construction	(Apple and Deisenroth, 1972)	PLANET	Flow cost
		(Block, 1978)	FATE	Flow cost Closeness
		(Chen and Kengskool, 1990)		Flow cost
		(Dowling and Love, 1990)		Flow cost
		(Drezner, 1987)		Flow cost
		(Edwards et al., 1970)	MAT	Flow cost
		(Gaston, 1984)		Closeness
		(Hales, 1984)	ALDEP	Closeness
		(Hassan et al., 1986)	SHAPE	Flow cost
		(Heragu and Kusiak, 1986)	FLAT	Flow cost
		(Lee and Moore, 1967)	CORELAP	Closeness
		(Lin et al., 1990)		Flow cost
		(Ketcham and Malstrom, 1984)	FLAG	Flow cost
		(Khator and Moodie, 1983)		Closeness
		(Muther and McPherson, 1970)	RMA	Closeness

Table 1.1: FLP solution algorithms and models (continued)

Approach		Reference	Model	Objective Input
Sub-optimal algorithms	Construction	(Neghabat, 1974)	Linear placement	Flow cost, Closeness
		(Nugent et al., 1968)	HC66	Flow cost
		(O'brien and Barr, 1980)	INLAYT	Flow cost
		(Parsaei and Morier, 1986)		Closeness
		(Parsaei and Galbiati III, 1987)		Closeness
		(Ziai and Sule, 1988)		Closeness
		(Zoller and Adendorff, 1972)	LSP	Closeness
	Improvement	(Allenbach and Werner, 1990)		Flow cost
		(Buffa et al., 1964)	CRAFT	Flow cost
		(Charumongkol, 1990)		Flow cost
		(Hitchings and Cottam, 1976)	TSP	Flow cost
		(Khalil, 1973)	FRAT	Flow cost
		(Nugent et al., 1968)	H63	Flow cost
		(Nugent et al., 1968)	HC 63-66	Flow cost
		(Nugent et al., 1968)		Flow cost
		(Picone and Wilhelm, 1984)	Revised Hillier	Flow cost
		(Shore and Tompkins, 1980)	COFAD-F	Flow cost
		(James and Ruddell Jr, 1976; Tompkins and Reed Jr, 1973)	COFAD	Flow cost
		(Vollmann and Buffa, 1966)	COL	Flow cost
	Hybrid	(Chamoni, 1987)	MICROLAY	Flow cost
		(Drezner, 1980)	DISCON	Closeness
		(Kaku et al., 1991)	KTM	Flow cost
		(Liggett and Mitchell, 1981)		Flow cost
		(Scriabin and Vergin, 1985)	FLAC	Flow cost Closeness
		(Scriabin and Vergin, 1985)		Flow cost

Table 1.1: FLP solution algorithms and models (continued)

Approach		Reference	Model	Objective Input
Sub-optimal algorithms	Graph theoretic	(Eades et al., 1982)	Wheel Expansion Algorithm	Adjacency
		(Foulds and Robinson, 1978)	Branch and Bound Algorithm	Adjacency
		(Foulds and Robinson, 1978)	Deltahedron Algorithm	Adjacency
		(Green and Al-Hakim, 1985)		Adjacency
		(Latif, 1991)		Adjacency
		(Leung, 1992)		Adjacency (flows and technological constraints)
Meta-heuristics algorithms	Neural network	(Yeh, 1995)		Construction cost Interactive cost
		(Yeh, 2006)		Adjacency
	Genetic algorithm	(Chan and Tansri, 1994)		Total materials handling cost
		(Hamamoto, 1999)		Maximize throughput rate Minimize travelling time per trip
		(Kochhar et al., 1998)	HOPE	Material handling cost
		(Kochhar, 1998)	MULTI-HOPE	Material handling cost
		(Mawdesley et al., 2002)		Material handling cost
		(Rajasekharan et al., 1998)		Flow cost
		(Lee et al., 2003)		Flow cost

Table 1.1: FLP solution algorithms and models (continued)

Approach		Reference	Model	Objective Input
Meta-heuristics algorithms	Simulated annealing	(Meller and Bozer, 1996)		Flow cost
		(Wang et al., 2001)		Total material handling cost
		(McKendall Jr et al., 2006)		Flow cost
	Tabu-search	(Abdinnour-Helm and Hadley, 2000)		Inter/intra-floor costs
		(Liang and Chao, 2008)		Cost Preference
		(Chiang and Kouvelis, 1996)		Flow cost
	Ant colony optimization	(Lam et al., 2007)		Interaction Flow cost
		(Hani et al., 2007)	ACO_GLS	Distance between location Flow cost between resource
		(Solimanpur et al., 2004)		Material handling distances
Expert system		(Abdou and Dutta, 1990)		Product variety and quantity Degrees of flexibility Level of automation Materials handling system Work-in-process Environmental considerations
		(Fisher and Nof, 1984)	FADES	Flow data Distance data Materials handling cost

Table 1.1: FLP solution algorithms and models (continued)

Approach	Reference	Model	Objective Input
Expert system	(Kumara et al., 1987)		Number of departments Departments areas
	(Kumara et al., 1988)	IFLAPS	Adjacency
	(Malakooti and Tsurushima, 1989)		Adjacency, Flexibility Materials handling cost Materials handling time
	(Sirinaovakul and Thajchayapong, 1994)		Flow cost Closeness
	(Sunderesh and Kusiak, 1990)	KBML	Flow cost Closeness
	(Malakooti and Tsurushima, 1989)		Materials handling cost Flexibility Materials handling time
Fuzzy systems	(Dweiri and Meier, 1996)		Distances Relationships between departments
	(Evans et al., 1987)		Closeness Importance of departments
	(Raoot and Rakshit, 1993)		Material flow Service Organizational links Environment Distance
	(Whyte and Wilhelm, 1999)		Adjacency
	(Deb and Bhattacharyya, 2005)		Flow cost Dead space Area required for development of layout

Table 1.1: FLP solution algorithms and models (continued)

Approach	Reference	Model	Objective Input
Intelligent hybrid systems	(Adedeji and Arif, 1996)	FLEXEPRET	Adjacency Flow cost
	(Chung, 1999)		Flow cost Flexibility and expansion
	(Elbeltagi and Hegazy, 2001)		Closeness Level of workflow Level of safety or environmental hazard User's preference
	(Aiello et al., 2006)		Material handling cost Adjacency Distance request Aspect ratio
	(Balakrishnan et al., 2003)	FACOPT	Flow cost

1.2.2 Facility Layout Design Models Characteristics and Objectives

Muther's systematic layout planning (SLP) was introduced in 1973 and has been a proven tool in providing layout design guidelines and widely used by facility planners (Muther, 1973). Designing a layout usually begins with an initial layout and proceeds by trials and errors in changing departments until it satisfies the considered relationship factors and restrictions. This procedure is strongly dependent on the opinion of facility planners and may depend on their desired relationships or closeness of departments. Many layout design models and computer programs are introduced in literature. The objectives of these models, when designing position of departments in a layout, can be classified under three groups.

1. Minimization Objectives

These layout design models aim to minimise: total material handling cost, space cost, rearrangement cost, travel time, travel distance, equipment flow, information flow, backtracking and bypassing, traffic congestion, or shape irregularities (Drira et al., 2007).

2. Maximization Objectives

The objective of these layout design models is to maximize the adjacency function which is defined as assessment of the proximity requested between two departments.

3. Multi-Objective

Some researchers have considered more than one objective. Rosenblatt (1979) presented a combined quantitative and qualitative approach to the facility layout problem. The two objectives are minimizing the material handling cost and maximizing a closeness rating measure. A heuristic algorithm is developed in this regards. The paper by Jacobs (1987) described a new system capable of solving detailed facility layout problems which allows the consideration of multiple objectives on the layout solution. Criteria related to weighted distance between interacting layout elements, the structure of the final layout design, the use of circulation space in the layout and the satisfaction of special adjacency requirements, are included in the formulation. Dweiri and Meier (1996) aimed at minimizing simultaneously the material handling flow and the equipment flow and the information flow. In the Chen (1999) paper, a new multi-objective heuristic algorithm for resolving the facility layout problem is addressed. It incorporates qualitative and quantitative objectives and resolves the problem of inconsistent scales and different measurement units.

Moreover, Aiello et al. (2006) discussed a layout problem to minimize the material handling cost and maximize an adjacency function for assessment of the proximity requests between two departments.

The layout design models cover various characteristics of facilities. These characteristics have impacts on layout design and discriminate the facility planning models. Drira et al. (2007) and Tam and Li (1991) addressed some of these charactristics as: production variety and volume, material handling system, different possible flows allowed for parts, number of floors on which the machines can be assigned, department shapes, and the pickup and drop-off locations.

Table 1.1 presents the well-known layout design models based on the FLP approaches, differences in characteristics and objectives of these models. As can be seen in this table, most of the models concentrate on objectives such as closeness and adjacency or material handling and flow cost. Other factors such as safety in the facility arrangements, travel time between departments, equipment and information flow, space and rearrangements costs, backtracking and bypassing, or traffic congestion are also important to be considered.

1.3 Risk Assessment

With the increasing costs of workers' compensation and litigation due to injuries, industries are becoming more interested in taking considerations to prevent accidents from occurring. The National Institute for Occupational Safety and Health (NIOSH) in US engaged 500 stakeholders from the occupational safety and health community to help define a national occupational research agenda (NORA) to improve worker safety and health (Goldenhar et al., 2001). Today, the ILO's SafeWork Programme on Safety, Health and the Environment is dealing with safety and productivity through health and safety at work, one of its tasks being to produce global statistics on occupational facilities and injuries (ILO, 2012). The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), was established in Quebec, to contribute through research to the prevention of industrial accidents and occupational diseases, and to the rehabilitation of affected workers (IRSST, 2010).

Many standards and regulations are also published to ensure worker safety and health at their working environment. A few examples of these standards are: the ISO11064-1 (2000) which concentrates on the ergonomic design of control centres. EN1005 (2003) is the guidance on the application of the essential health and safety requirements on ergonomics of machine directives. ISO11228-1 (2003) specifies recommended limits for manual lifting and carrying while taking into account, respectively, the intensity, the frequency and the duration of the task. MIL-STD-1472F (1999) establishes general human engineering criteria, principles and practices for design and development of military systems, equipment and facilities. MIL-STD-882D (2000) addresses an approach for the management of environmental, safety, and health mishap risks encountered in the development, test, production, use, and disposal of Department of Defense systems, subsystems, equipment, and facilities. ISO12100 (2010) specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. ISO14121-1 (2007) provides guidance on the information that is required to enable risk assessment to be carried out for safety of machineries. ISO/TS14798 (2006) provides a process for making decisions relevant to the safety of lifts during the design, construction, and installation.

In general, any improvement to the safety of a working environment or situation begins with risk assessment (Giraud, 2009). Hence, OHS risk assessment is the core of safety practices in any industry. Various risk assessment tools exist for different aspects of OHS (e.g., ergonomics, environmental, chemicals, machineries, etc.). As an example, Chiasson (2012) has analysed six common methods among practitioners for assessing risk factors for musculoskeletal disorders (MSDs) of the back, namely: QEC (Quick Exposure Check), Ergonomic Workplace Analysis of the FIOH (Finnish Institute of Occupational Health), 3D SSPP, 4D WATBAK, A Guide to Manual Materials Handling by Mital et al. (1997), and the EN 1005-3 standard. In regards to the environmental risk assessment, Carpenter (1995) presents environmental impact assessments (EIA) and environmental risk assessment (ERA) tools to advice managers and decision makers about the frequency and severity of adverse consequences to the environment from their activities or planned interventions. Consequently, changes can be made to mitigate or eliminate the impact or to reduce the risk; e.g., to use a different site or alternative technology, to implement risk management or emergency response capability. Many risk assessment tools for machine safety exist as well, such as: SUVA (Bollier and Meyer, 2002), BT (Worsell and Wilday, 1997), Gondar (GondarDesign, 2000), Nordic (Mortensen, 1998), etc. The main concentration in the rest of this chapter is on risk assessment tools for machine safety.

Generally, risk assessment consists of a series of steps to inspect the existing hazards. According to Main (2004a) and as referenced in ISO12100-1 (2003), this process includes a risk analysis, followed by a risk evaluation. Risk analysis involves: determining the limits of the situation, risk identification, and estimating the risk; while risk evaluation allows making decisions in regards to the safety and changes in the situation. Risk assessment is a complex process that entails the consideration of many parameters, which are difficult to quantify (Pinto, 2014). Paques et al. (2007) illustrates the risk assessment process as shown in Figure 1-2.

1.3.1 Risk Identification Methods

Paques et al. (2005) collected 275 documents describing methods and tools for assessing risks associated with the industrial machines as well as the military, nuclear and aeronautics industries. The 108 methods applicable for assessing the risks associated with these industrial machines were analysed in their research. Wassell (2008) provided a concise description of current risk identification methods and their limitations. His research was purposed to identify gaps and opportunities for improvement in risk identification through the literature search.

Moreover, Parry (1986) described the underlying principles and philosophy of hazard identification techniques, their use and limitations. The research reviewed various techniques that are available for identifying hazards associated with the processing, storage and handling of dangerous substances, applicable to machines with similar guides but different parameters; i.e. HAZOP, Checklists, FMEA, Fault Tree Analysis, Event Tree Analysis and Cause-Consequence Analysis.

1.3.2 Risk Estimation Tools

In order to estimate the risk degree for the identified hazards, many methods and tools are presented in different forms. One of the distinguished studies in recognizing risk estimation tools is the literature reference document by Worsell and Ioannides (2000). Chinniah et al. (2011) theoretically compared the performances of tools in estimating risks and evaluated whether they estimate the risks uniformly. 31 qualitative tools used for risks estimation associated with industrial machines were analysed. Their risk estimation parameters were compared and different tools were applied to estimate the risks associated with 20 hazardous situations. Results indicated that the structure of tools and terminology can potentially lead to biased or incorrect risk estimations. Abrahamsson (2000) analysed various quantitative risk estimation tools in different contexts and particularly in the occupational exposure to hazardous substances. The research concentrated exclusively on the analysis of different types of uncertainty associated with risk estimation tools. Paques et al. (2007) classified and presented the main quantitative results of the analysis of 108 methods and tools which are applicable for assessing the risks associated with industrial machines.

The risk estimation tools can be categorized based on different factors. Chinniah et al. (2011) addressed some of these factors as: diversity in the nature of each risk estimation tool; definition and number of parameters; techniques to calculate the risk and evaluate the final result.

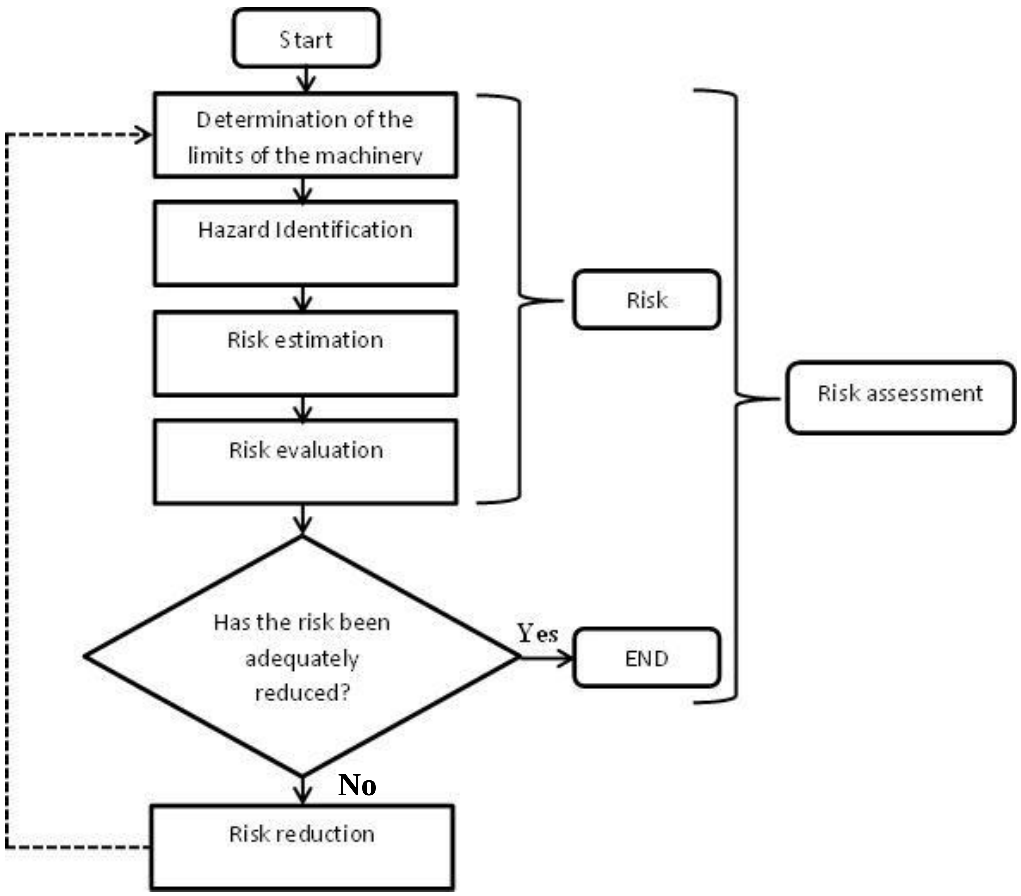

Figure 1-2: Risk assessment process – retrieved from Paques et al. (2007)

Risk Estimation Parameters

For estimating the risk associated with a particular hazardous situation, different parameters should be evaluated. Traditionally, risk estimation is based on collecting and evaluating data on severity of an injury and probability of occurrence of the event. In ISO/IEC-Guide51 (2005), risk is interpreted as comprising two parameters of severity and probability. ISO12100 (2010) presents the probability of occurrence of harm as the combination of: frequency and duration of exposure, probability of occurrence of a hazardous event, and possibility of avoiding or limiting the harm.

Moreover, different levels of measurement are considered for each of the risk estimation parameters. Chinniah et al. (2011) conducted a comprehensive study on defining the equivalence scales for the parameters and their risk levels for the risk estimation tools. These parameters and their measurement levels vary for different risk estimation tools. Table 1.2 addresses 38 common risk estimation tools among industries, and presents their prospect in regards to the type of risk parameters used. These tools are mainly applied to machine safety, since these tools were collected from previous studies; e.g., Chinniah et al. (2011); Main (2004b); Worsell and Ioannides (2000); Worsell and Wilday (1997).

Table 1.2: Risk estimation tools and parameters

Risk estimation tools	**Reference**	**Severity of harm**	**Probability of occurrence of harm**	**Frequency and duration of exposure to hazard**	**Frequency of exposure to hazard**	**Duration of exposure to hazard**	**Probability of occurrence of a hazardous event**	**Technical and human possibility of avoiding or limiting harm**	**Other parameters**
ANSI B11 TR3- machine safety	(ANSI-B11.TR3, 2000)	✓	✓		✓				✓
AS/NZ 4360- OHS	(AS/NZ4360, 2004)	✓		✓					
Australia Environment	(Main, 2004b)	✓		✓					
BASF-chemical processes	(Ruge, 2004)	✓					✓		
BS8800-OHS	(BritishStandard, 1996)	✓	✓						✓
BT-machine safety	(Worsell and Wilday, 1997)	✓	✓						✓
CBA- OHS	(Worsell and Ioannides, 2000)	✓							✓
SICK SCRAM- OHS	(Gornemann, 2003)	✓			✓	✓	✓	✓	
CSA Q634- OHS	(CSA-Q634-91, 1991)	✓		✓					
CSST- machine safety	(CSST, 2006)	✓		✓			✓	✓	
SUVA- machine safety	(Bollier and Meyer, 2002)	✓	✓	✓			✓	✓	
Systems of Safety	(Etherton, 2007)	✓			✓	✓			✓
DEF STAN 00-56	(Worsell and Ioannides, 2000)	✓	✓						
European Standard EN 1050	(Etherton, 2007)	✓	✓	✓			✓	✓	
Gondar- machine safety	(GondarDesign, 2000)	✓					✓		
HSE Construction	(Main, 2004b)	✓		✓					
HSL- OHS	(HSL, 2000)	✓			✓			✓	
IGE- equipment safety	(Worsell and Ioannides, 2000)	✓		✓					
ISO/TS 14798- material handling	(ISO/TS14798, 2006)	✓	✓						

Table 1.2: Risk estimation tools and parameters (continued)

Risk estimation tools	**Reference**	**Severity of harm**	**Probability of occurrence of harm**	**Frequency and duration of exposure to hazard**	**Frequency of exposure to hazard**	**Duration of exposure to hazard**	**Probability of occurrence of a hazardous event**	**Technical and human possibility of avoiding or limiting harm**	**Other parameters**
ISO 14121- OHS	(Etherton, 2007)	✓	✓	✓			✓	✓	
Job Safety Analysis	(Etherton, 2007)	✓	✓						
Kazer-machine safety	(Worsell and Wilday, 1997)	✓	✓						
MER Risk Graph-machine safety	(Worsell and Wilday, 1997)	✓		✓			✓	✓	
MIL-STD-882D-system	(MIL-STD-882D, 2000)	✓	✓						
MISRA- OHS	(Worsell and Ioannides, 2000)	✓							✓
Nordic- machine safety	(Mortensen, 1998)	✓	✓		✓		✓	✓	
Ontario PG- hydroelectric systems	(Froats and Tanaka, 2004)	✓							✓
Raafal Risk Calculator	(Worsell and Wilday, 1997)	✓		✓			✓		
Raffal Matrix-machine safety	(Worsell and Wilday, 1997)	✓					✓		
Railway	(IEC/TR62278, 2001)	✓					✓		
Rototic Industry	(ANSI/RIA.R15.06, 1999)	✓			✓			✓	
R3- OHS	(Etherton, 2007)	✓		✓			✓		
Queensland Metal	(QueenslandMetal, 2002)	✓	✓						
US CPSC- OHS	(Main, 2004b)	✓	✓						
US Army	(Main, 2004b)	✓					✓		
US Navy	(Main, 2004b)	✓					✓		
Wells SCRAM- machine safety	(Worsell and Wilday, 1997)	✓					✓		
29CFR1910.119-process	(Etherton, 2007)	✓	✓						

1.4 Literature Review on Integrating OHS in Facility Planning Models

Due to the possible high cost in terms of human suffering and lost production, a business should place particular emphasis on safety factors. The majority of previous research in facility layout planning has focused on optimizing movement costs or the closeness relationship among departments so that the costs are minimized. However, providing safe and pleasant environment for personnel should be considered as early as when designing the layout of a facility.

The relationship between facility layout design and safety concerns is not considered extensively in developing the methodologies and models. Fernandez-Muniz et al. (2007) suggested a Safety Measurement System Scale based on the results of a questionnaire survey of 455 Spanish companies, to be used to guide the safety activities of organizations. Chang and Liang (2009) developed a model, based on a three level multi-attribute value model approach, in order to evaluate the performance of process safety management systems of paint manufacturing facilities. Terrier (2003) presented a guideline to take into account the risk of accidents and occupational diseases in the design phase of workplace implementation. This would enable avoiding unsatisfactory and technical difficulties in future improvements. Tompkins (2010) presented the human factor risks as one of the criteria to be considered in the prioritization matrix for facilities design. In developing facilities design alternatives, designers need to consider the human factor risks. In that matrix, this criterion is compared using weights with other criteria such as the total distance travelled, manufacturing floor visibility, overall aesthetics, space requirements, people requirements etc. Harms-Ringdahl (1987) performed a case study involving analysis of layout, transport system, machines, and a number of different activities in order to do safety analysis at a paper mill. The results of safety analysis were evaluated with respect to the accident which had happened and demonstrated safety analysis being an effective tool to decrease occupational risks. The use of risk analysis when designing a facility is mentioned by Brauer (2006). The author argues that the best time to incorporate safety into a facility is during the planning and design of a new facility or the modernization of an existing facility. A tool consisting of a list of safety considerations in facility planning is also presented.

Several mixed integer linear programming models have been proposed to reduce financial costs while considering safety aspects inevitably included in these models; e.g., Papageorgiou and Rotstein (1998); Patsiatzis et al. (2004); Patsiatzis and Papageorgiou (2002); Penteado and Ciric (1996). Few artificial intelligent techniques have been proposed which consider both quantitative and qualitative factors, including safety and ergonomics. As such is the study by Pham and Onder (1992) who have developed a knowledge-based system for optimum working environment design. This combination of knowledge-based technology, genetic optimization methods, and database technology has proved to be an effective way to build powerful knowledge-based systems for solving complex ergonomic design problems. Pham and Onder (1991) have proposed an expert system for ergonomic working environment design by using a genetic algorithm approach. Penteado and Ciric (1996) presented a new mixed-integer nonlinear optimization approach to process plant layout that integrates safety and economics. Their proposed approach identifies safe and economical layouts by minimizing overall costs for chemical plants. In the research by Carnahan and Redfern (1998), a genetic algorithm model is applied to the problem of designing safe lifting tasks within the constraints of the work place. In the article by Elbeltagi and Hegazy (2001), a construction site layout planning system was developed incorporating a knowledge base to identify and size the required facilities on a site, a fuzzy quantifier to identify the facilities' closeness weight, and a modified genetic algorithm to optimally place facilities on the construction site. The work flow, safety concerns, and user preference of having facilities adjutant are considered.

CHAPTER 2 RESEARCH APPROACH AND STRATEGY

This chapter examines the main characteristics of the research design that outline how the research questions are investigated through the research contributions. It exposes the proposed conceptual model and the related research propositions. The research methodologies are justified and the overall structure of the dissertation is determined by presenting the four dissertation articles.

2.1 Problem Statement

Designing the layout of a facility constitutes an important fact to be faced by facility planners. While the main concern in facility planning is to reduce the cost of material handling, layout design plays a major role in safety and productivity of operations. Previous research has little contribution in including OHS aspects in facility layout design. Facility planning reference books such as Tompkins (2010) has slightly reflected on safety related objectives of facilities planning model so that the location of departments are adopted to promote the ease of maintenance as well as providing safety and job satisfaction for workers. However, no specific measure is presented in order to directly include the safety aspects in facility planning models. This is despite the need for preventing or minimizing accidents through proper layout designs.

Additionally, studies have been conducted to assess safety issues in different facilities (e.g., Chang and Liang (2009); Fernandez-Muniz et al. (2007); Harms-Ringdahl (1987)). The main safety aspect considered in these studies is ergonomics. Embracing other aspects of safety, such as environmental issues or machine and movement related factors, are equally important and should be taken into consideration when designing a layout.

Therefore, there is a need for developing a new facility planning model, in which, various OHS aspects are significantly assessed when designing a layout. The scope of this research is on evaluating OHS aspects in planning new facilities or their redesign. Nevertheless, the originality of this research is considering safety at the same level as more traditional factors such as cost, productivity, space, or innovative improvements in facility planning and design.

Research Questions

The main objective of this research is to clarify OHS aspects related to facility planning and layout design. Answers to the following research questions are provided:

RQ1: What are the OHS factors that need to be considered in facility planning?

This research question identifies different OHS factors which need to be considered for designing a layout. An OHS guideline is introduced through literature review. This guideline can be used by facility planners as a checklist to evaluate the safety related factors in an existing facility or the ones that need to be considered when designing a new layout. Chapter 3 (Moatari-Kazerouni et al., 2012) presents this guideline. The guideline is applied to a hospital kitchen and the results are presented in Appendix A (Moatari-Kazerouni et al., 2013).

RQ2: How can OHS factors be quantified?

Risk estimation is used to quantify risk associated with OHS. An improved risk estimation tool which quantifies risk in a facility is developed based on the findings of previous studies. The literature has presented a large number of risk estimation techniques, while recent studies have revealed that some techniques have serious flaws. Chapter 4 (Moatari-Kazerouni et al., 2014c) presents an improved risk estimation tool which avoids many of these flaws.

The OHS guideline can be used to identify the risk scenarios in a facility. The improved risk estimation tool can quantify the risk value of these scenarios. This tool constitutes a first step towards the integration of OHS concerns in facility layout planning models.

RQ3: How can OHS factors be integrated in the facility planning models?

This question investigates how the existing facility planning models can be modified in order to provide a more robust methodology that meet productivity and safety requirements. In this regard, the improved risk estimation tool is integrated in an existing facility planning model. Chapter 5 (Moatari-Kazerouni et al., 2014a) proposes the facility layout planning model which integrates OHS in layout design, so that the safety concerns are reflected prior to the construction of a facility. This model considers transportation cost as well as safety concerns in a facility. Chapter 6 (Moatari-Kazerouni et al., 2014b) illustrates the application of the proposed model in designing a new layout for a hospital kitchen.

2.2 Research Design

As noted by Creswell (2009), if a concept needs to be understood because little research has been conducted on that, it merits a qualitative research approach. Qualitative research is exploratory and is useful when the researcher does not know the important variables to examine, the topic is new, it has never been addressed with a certain sample or group of people, or existing theories do not apply with the particular sample or group under study (Morse, 1994). Since it is the case in this PhD research, the qualitative methodologies are employed.

The approach taken in this research is a combination of literature review and conducting empirical case studies. Literature reviews helped limiting the scope of the research inquiry and expressing the importance of studying the topic. During the empirical studies, a qualitative approach is taken where the observation and interview research methods are applied. Application of these methodologies is elaborated in the following sections.

2.2.1 Case Study

A case study is an empirical inquiry of in-depth and within the real life context, especially when the boundaries between phenomenon and context are not clearly evident. It can take both qualitative and quantitative stances, whereas highly versatile and employs any and all methods of data collection, from testing to interviewing (Yin, 2003).

A case study was conducted in this research. The objectives in this exploratory study were to answer the research questions. It was executed in a kitchen of a hospital in Montreal, Canada. The kitchen was designed in early 19's. Although few improvements were implemented throughout time; recently, renovation of the kitchen layout was suggested in order to provide additional services such as the room services. Hence, changes in the layout design of the kitchen were necessary. Given that OHS is one of the important issues to be considered at a hospital and specifically in a kitchen, this research provided an evaluation of OHS considerations for the new layout design. Two research methodologies are used in this regards, observations and interviews.

2.2.2 Observation

Observation is a research methodology in which the researcher takes field notes on the behaviour and activities of individuals at the research site. In these field notes, the researcher records activities at the research site, in an unstructured or semi-structured way (Yin, 2003). The observation and taking field notes were used in order to identify the OHS concerns.

2.2.3 Interview

In interviews, the researcher conducts face-to-face or over phone interviews with participants. These interviews involve unstructured and generally open-ended questions that are few in number and intended to elicit views and opinions from the participants (Yin, 2003). Semi-structured interviews were conducted among the kitchen personnel.

2.3 Research Contributions

The research conducted for this dissertation has been presented in the following original contributions:

- Moatari-Kazerouni, A., Agard, B., Chinniah, Y.; A Guideline for Occupational Health and Safety Considerations in Facilities Planning; *Proceeding of the 4th International Conference on Information Systems, Logistics and Supply Chain (ILS 2012)*; Quebec, Canada.
- Moatari-Kazerouni, A., Chinniah, Y., Agard, B.; A Proposed Occupational Health and Safety Risk Estimation Tool for Manufacturing Systems; *International Journal of Production Research*; Status: Published Online (August 2014); DOI:10.1080/00207543.2014.942005.
- Moatari-Kazerouni, A., Chinniah, Y., Agard, B.; Integrating Occupational Health and Safety in Facility Layout Planning, Part I: Methodology; *International Journal of Production Research*; Status: Published Online (October 2014). DOI: 10.1080/00207543.2014.970712.
- Moatari-Kazerouni, A., Chinniah, Y., Agard, B.; Integration of Occupational Health and Safety in the Facility Layout Planning, Part II: Design of the Kitchen of a Hospital; *International Journal of Production Research*; Status: Published Online (October 2014). DOI: 10.1080/00207543.2014.970711.

2.4 Research Approach

Figure 2-1 proposes the conceptual framework arising from the problem statement, the research questions, and the literature review. It can guide subsequent research activities.

This research investigated the possibility of integrating OHS factors in facility planning and layout design. To this end, the two subjects of facility planning and OHS were studied in detail. Facility planning was examined in regards to different aspects of layout design, FLPs, and specifications of the models for solving FLPs. From the broad topic of OHS, safety factors regarding machines and maintenance, environmental hygiene, ergonomics, material handling and movements, material and substances, and the infrastructural design of a facility were studied. In addition, various characteristics of risk estimation tools, mainly the tools used for machine safety, were investigated.

The theoretical knowledge and literature review results, obtained from comprehensive research on the two subjects of facility planning and OHS, identified the existing flaws and facilitated responding the research questions. The research questions were raised to, firstly, introduce a risk estimation tool that can quantify OHS factors, and secondly, propose a method to integrate OHS factors in facility planning models. They are manifold as explained in following paragraphs.

2.4.1 A Guideline for Occupational Health and Safety Considerations in Facilities Planning

To respond to the first research question, an OHS guideline was designed for facility planners when designing a layout. This was done through reviewing the literature as well as the safety guidelines and standards, and collecting the OHS factors which feature facility planning and layout design. A comprehensive list of safety criteria was presented under 6 categories of (1) safety policies reflecting the hazards caused by machineries and equipment; (2) safety in designing the material handling system, machinery and equipment movement; (3) employees training, experience and flexibility of jobs; (4) safety in maintenance and services; (5) type and characteristics of the products and material used in the manufacturing process; and (6) environmental aspects of safety. The outcome of this study was presented as a peer reviewed conference paper and is reported in Chapter 3. While the presented guideline can be used as a safety audit checklist for facility planners, it demonstrates the first step in identifying the risk scenarios in a facility. An application of this guideline is considered to evaluate the layout of a kitchen hospital and identify the existing safety issues (Appendix A).

2.4.2 A Proposed Occupational Health and Safety Risk Estimation Tool for Manufacturing Systems

In order to respond to the second research question, the literature review research methodology was used to collect information regarding different characteristics of risk estimation tools. The majority of reviewed tools are the ones applied to machine safety, because they were collected from a previous study (Chinniah et al., 2011) which investigates machine safety risk estimation tools. Different characteristics of these tools were studied and compared in order to identify (i) a comprehensive set of risk parameters and levels, and (ii) a calculation method to quantitatively measure the risk value. An improved risk estimation tool is developed (Chapter 4). The risk scenarios, developed by means of the OHS guideline (Conference Paper), can be further assessed via the improved risk estimation tool. It can evaluate the risk associated with various hazardous situations and is able to assign a numerical value to their risk.

2.4.3 Integrating Occupational Health and Safety in Facility Layout Planning, Part I: Methodology

To answer the second research question, a facility planning model is proposed in which OHS factors are integrated. Literature reviewing of facility planning models is considered as the research methodology in this section. The traditional model of designing a layout was chosen as the base of the proposed model. In order to integrate OHS aspects in this model, the improved risk estimation tool (Article I) was used. An integrated OHS-facility planning model is proposed (Chapter 5). This model consists of 4 steps and can regard cost and safety aspects within the same importance level.

2.4.4 Integration of Occupational Health and Safety in the Facility Layout Planning, Part II: Design of the Kitchen of a Hospital

The proposed OHS-facility planning model in Chapter 4 was implemented in a case study at the kitchen of a hospital (Article 3). Considering safety at a hospital, and its kitchen in specific, is very important in order to ensure the safety and health of the consumers as well as the personnel. The food preparation and distribution at the hospital kitchen can be treated as a production line of a manufacturing setting. Observations and interviewing the kitchen personnel were the two data collection methods for gathering information. The OHS guideline (Conference Paper) assisted throughout the data collection. Risk scenarios, associated with the existing layout of kitchen, were developed and their risk values were estimated by using the improved risk estimation tool (Article 1). A new layout design was proposed by applying the proposed OHS-facility planning model (Article 2). The new layout demonstrates a safer environment for the kitchen personnel and is lower in terms of material handling costs.

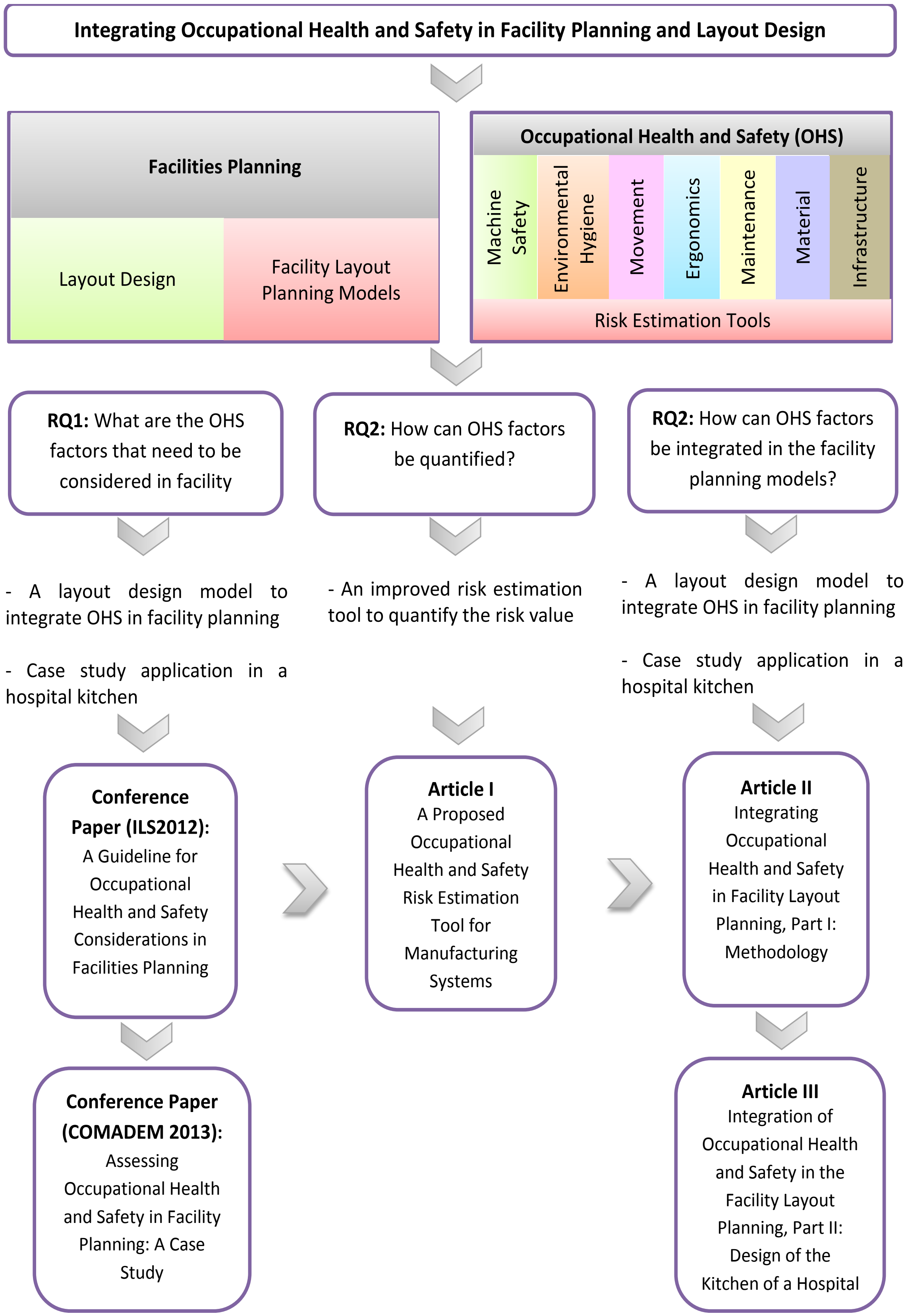

Figure 2-1: Conceptual Model

To summarize, the research questions are addressed by reviewing the literature in order to specify OHS factors for facility planning as well as the risk estimation tools and facility planning models which are currently used by companies. An OHS guideline is presented for facility planners (Conference Paper). The risk scenarios, developed via using the OHS guideline, are quantified with the proposed improved risk estimation tool (Article I). This tool is further used to integrate OHS factor in layout planning models (Article II). The proposed OHS-facility planning model is examined through a case study (Article III). Figure 2-2 shows the research phases throughout this PhD which have resulted in the three contributed articles and the conference paper; the relations among them are demonstrated.

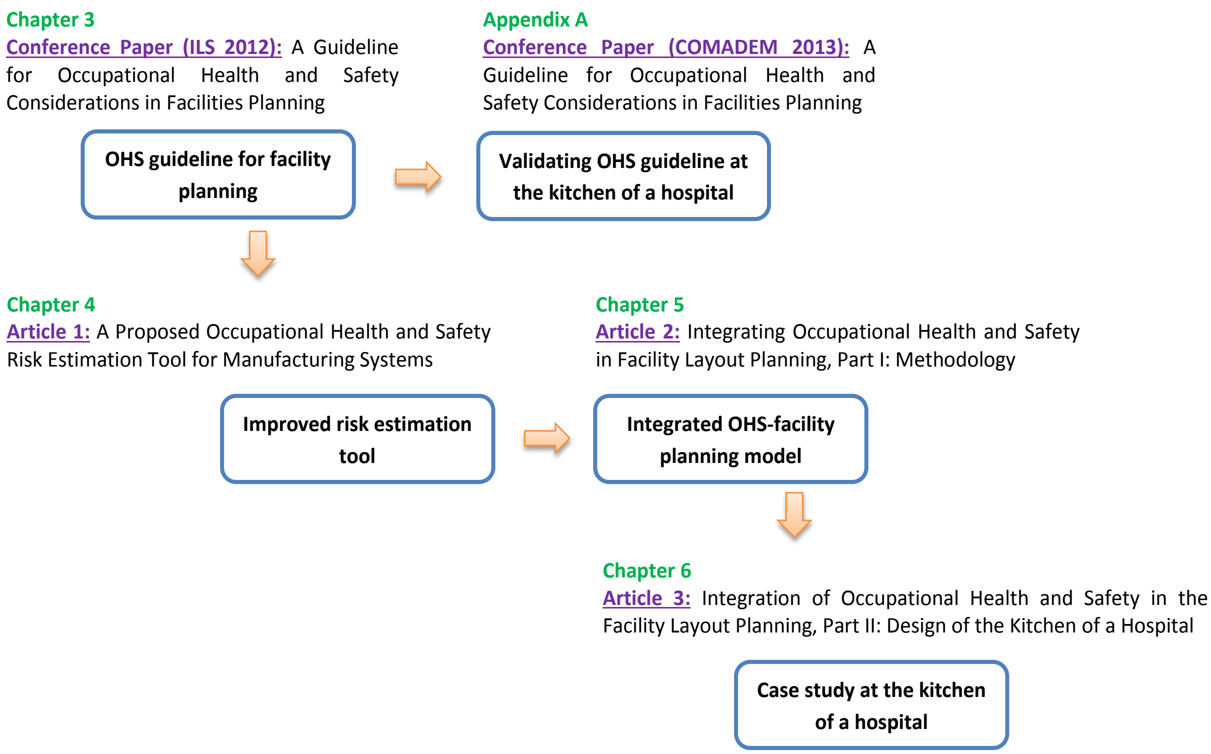

Figure 2-2: PhD phases and research contributions

CHAPTER 3 A GUIDELINE FOR OCCUPATIONAL HEALTH AND SAFETY CONSIDERATIONS IN FACILITIES PLANNING

Abstract[1]

Facilities layout planning is fast becoming the compliance for the organizations. In the past two decades, researchers have developed simulation and mathematical programming models to estimate the performance measures of a production system. However, the considerations of occupational health and safety management have been overlooked.

The objective of this work is to develop a comprehensive list of safety criteria which facility managers need to consider at the early stages of the plant design in order to improve occupational health and safety. These criteria, which are based on previous research as well as the safety guidelines and standards, provide a tool for anticipating hazardous situations and instructing the improvements to reduce the occupational accidents. Furthermore, a structured safety outline for facilities planning will prevent future potential layout modifications for safety reasons and consequently reduce costs.

Keywords: Facilities layout planning, occupational health and safety, safety criteria

3.1 Introduction

Industrial and manufacturing companies are facing many problems in today's competitive environment (Gopalakrishnan et al., 2004). Customers expect excellent quality product, low-priced and creativity in response to their needs (Pine and Davis, 1999). To attain these objectives, companies have to focus on possible improvements, productivity, quality, resource, space, and reducing wasting-time (Wang, 2010). Selecting a good layout, which is defined as the physical arrangement of machines, personnel, raw materials and finished goods (Roslin et al., 2008), is a

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[1] Moatari-Kazerouni, A., Agard, B., Chinniah, Y.; (2012); A Guideline for Occupational Health and Safety Considerations in Facilities Planning; *Proceeding of the 4th International Conference on Information Systems, Logistics and Supply Chain (ILS 2012)*; Quebec, Canada.

critical decision in facilities planning, since the layout selection will serve to establish the physical relationships between activities. A well-designed plant can minimize the amount of land occupied and the movements in a process while maintaining easy access to spaces around individual units and providing safety zones between them. It not only reduces investment costs but also avoids or minimizes safety and maintenance problems (Penteado and Ciric, 1996).

Efficient facilities layout is essential in any industrial sector in order to improve quality, productivity, and competitiveness of an industry (Russell and Taylor, 2000). The facilities layout's goal is to provide the best arrangement of process equipment in the plant. Therefore, the criteria for evaluating a good layout necessarily relates to personnel, materials, machines and their interactions. While the different design of a plant layout has generally been recognized as one of the most important solutions for the facilities layout problems, a company can reach its goals by emphasizing the layout design and creating a layout model (Rawabdeh and Tahboub, 2006).

On the other hand, a company contains a large number of systems which interact to achieve the business objectives (Waeyenbergh and Pintelon, 2002). Occupational health and safety (OHS) contributes more than ever to the achievement of these objectives. Indeed, proper OHS consideration ensures regulatory compliance, improves productivity and wellbeing of personnel, keeps the cost down by avoiding stoppage time following accidents and investigation; OHS contributes positively to the overall performance of the company (Jallon et al., 2011a, b).

Furthermore, safety is a cross-disciplinary area concerned with protecting the safety, health and welfare of people engaged in work environment or employment (Chang and Liang, 2009). There are some basic ways to improve the safety in a plant; inherent safe design aims at eliminating the hazards. If this approach is not possible, the risk associated with hazards can be reduced by engineering solutions, safe working methods, information and training. However, taking into consideration the safety concerns related to the working environment of the company as early as in the design stage of the facilities layout can be a preventive solution.

The majority of previous research in facilities layout planning has focused upon optimizing movement costs, site costs, and qualitative preferences (Tompkins, 2010). The relationship between facilities layout and occupational safety has not been researched extensively. Chang and Liang (2009) developed a model, based on a three level multi-attribute value model approach, in order to evaluate the performance of process safety management systems of paint manufacturing facilities. Fernandez-Muniz et al. (2007) developed a Safety Measurement System Scale based on the results of a questionnaire survey of 455 Spanish companies, to be used to guide the safety activities of organizations. Penteado and Ciric (1996) presented a new mixed-integer nonlinear optimization approach to process plant layout that integrates safety and economics. Their proposed approach identifies safe and economical layouts by minimizing overall costs for chemical plants. Broberg (2007) described the concept of workspace design as a potential new approach for ergonomists and other OHS consultants. Shikdar and Sawaqed (2003) identified factors that affected workers' productivity and OHS. Lack of skills in ergonomics and training, communication and resources are believed to be some of the factors contributing to the poor ergonomic conditions and consequent loss of worker productivity and reduced health and safety in these industries.

Nevertheless, in most literatures, health and safety issues are considered from the ergonomic aspect versus the facilities layout design. However, other factors such as: safety of material handling systems, machineries, environmental concerns, etc. are also important. The main objective of this paper is to explicit safety considerations related to facilities layout planning features. We provide recommendations for the following research question:

What are the relevant facilities planning factors that features OHS criteria?

In this concern, a comprehensive list of safety criteria is developed and discussed. Our recommendations are derived from information generated through literature reviews. This approach is used to identify, propose and discuss safety criteria that need to be considered when implementing a facilities layout. Thus, OHS needs to be considered during the early stages of the plant layout design. Facilities layouts are developed and modified several times during the design process. Using a structured methodology for facilities layout which incorporates OHS can minimize the number of trial and error revisions of layouts resulted from safety considerations; hence reduce costs attributed to modifications. Ultimately, the outcomes enrich the methodologies of facilities layout planning by incorporating OHS considerations.

3.2 Occupational Safety Management

In the last 20 years, safety management at industrial facilities have evolved from conventional safety audits and passive compliance to laws and regulations to a proactive approach such as the establishment and the execution of systematic safety management system (Chang and Liang, 2009). According to Kharbanda and Stallworthy (1988), safety is a concept covering hazard identification, risk assessment and accident prevention. Risk assessment is the process of systematically guiding risk reduction and management activities based on collecting and evaluating data on severity of a harmful event and probability of occurrence of that harm. Depending on function and operating mode, safety requirements can vary in different facilities layouts.

Previous research and literature reviews demonstrate different tools and methods for assessing risk while it is not easy choosing the tool best adapted to the needs of each company. Wassell (2008) presented a coherent and concise description of current methods for risk identification and describes their limitations. His research proposed identifying gaps and opportunities for improvement in risk identification through the literature search. Chinniah et al. (2011) researched to theoretically compare the performances of tools in estimating risks and to evaluate whether they estimate the risks uniformly. 31 qualitative tools used for estimation risks associated with industrial machines, following the ISO 14121-1:2007 guidelines, were analysed by comparing their risk estimation parameters as well as applying the different tools to estimate risks associated with 20 hazardous situations. Abrahamsson (2000) attempted to analyse various quantitative risk estimation tools particularly in the occupational exposure to hazardous substances. His research focused exclusively on the analysis of the various types of uncertainty associated with the tools. Above all, safety should always come first and remain so, despite of its costs. Good design and forethought can often bring increased safety at less cost (Heikkila, 1999).

3.3 Methodology and Results

This research is built upon a comprehensive list of safety criteria. These criteria were basically generated from literature reviews on the subject and were classified under six major facilities planning factors, introduced by the authors. These factors and their 20 safety criteria are listed in Table 3.1. A detailed description of each safety criteria is provided in the following sections.

Table 3.1: Facilities planning factors and related safety criteria

	Safety Criteria
Machine	1. Placement and distance of machines according to each other 2. Standardization in using machineries and equipments 3. Degree of automation 4. Storage space
Movement	5.Material handling load, method and equipment 6. Movement of machinery, machine part and equipment 7. Minimum aisle width
Workforce & Ergonomic	8. Training, education and labour experience 9. Self-inspection and personal protection 10. Job flexibility 11. Safe Access to machineries 12. Ergonomic hazards
Maintenance & Services	13. Access to machines for setting, maintenance or repair 14. Machine safeguards flexibility and machine guard removal
Material	15. Characteristics of product
Environment	16. Noise disturbance 17. Electricity or released of stored energy 18. Temperature and pressure, radiation, fire and explosion 19. Illumination 20. Respiratory hazards

3.3.1 Machine

Ever since machinery was first developed to help man with his labours, a heavy price in injuries and damage has been paid for the convenience. This safety factor deals with some of the principals involved in providing safety in oppose to the common hazards caused by machineries and equipment.

1. Placement and distance of machines according to each other

In order to plan for machineries placements, machine specifications, space size and safety requirements must be considered. Space and equipment considerations include machine dimensions, power, dedicated circuits, etc. Regarding the aspects of space limits, one should:

- Consider the range of movement. Sufficient spaces have to be allocated in order to avoid hazardous zones, e.g., entrapment between moving part of equipment and fixed fixtures of the plant or adjacent equipment;
- Consider space requirements for the person interacting with the machine, such as during operation and maintenance. Postures for operators and mechanics are linked to availability of space;
- Consider the human interactions such as the operator-machine interface. The control panels need to be allowing clear view of the equipment in order to avoid blind spots and create potential hazardous zones;
- Consider the machine-power supply interface. The equipment need to have its own power supply and energy isolating devices in order to isolate the equipment without affecting the adjacent one if needed. The use of local isolating devices makes it more convenient and more prone to the application of lockout procedures. The isolating devices have to be easily accessible and machine layout need to take this into consideration.

2. Standardization in using machineries and equipment

Many dangerous accidents are caused by the incorrect use of machinery, equipment and tools. The following guidelines are to be followed (MIT, 2004):

- Use of machinery, equipment and tools must be restricted to authorized personnel who have the proper training on safe working methods;
- Use proper and safe tools for the job and use it in accordance with the manufacturer's instructions, ensuring that guards and safety devices found on equipment are used;
- Before undertaking maintenance or repair on any plant, equipment or tools, apply lockout procedures (i.e., turn off equipment, switch off the power and disconnect the drives, apply locks and or tags to isolating devices, dissipate residual energies, verify absence of energies);

- Switch off electric tools and allow them to stop revolving before laying them down or making any adjustments;
- Ensure that equipment, machinery or tools are in good condition before using;
- Before using power tools check that an electrician has inspected and tested the tools quarterly;
- Check that cables, plugs and insulation are undamaged;
- Wear protective clothing and equipment provided such as goggles and face masks.

3. Degree of automation

In addition to advantages such as greater productivity, reduced production costs, improved product quality and greater manufacturing flexibility, automated systems often eliminate the need for repetitive, tedious and hazardous tasks. Under normal operating conditions, workers do not access danger zones and are kept away from many hazards since the automated machines, often controlled by programmable logic controllers are designed to operate without human intervention. These automated systems should inherently improve safety by eliminating the need for workers to reach into danger zones. Furthermore, since fewer workers are needed in automated factories, it could be argued that potentially fewer workers are at risk (Chinniah et al., 2007; Goetsch, 2008).

Despite this, every new tool developed to enhance the ability of humans to work efficiently and effectively has brought with it a new safety and health hazard (Goetsch, 2008):

- Pay special attention to the numerous hazards which are not always easy to identify and coming from the use of multiple technologies (hydraulic, electric, pneumatic and mechanical) working simultaneously;
- Pay attention to potentially dangerous tasks, including maintenance, setting, commissioning, training, material loading/unloading, tool changes or adjustments during production, removal of jammed materials, and repairs or interventions following malfunctions;
- Consider the human errors such as miscommunication between workers who mistakenly energize or start a machine when a co-worker is in the danger zone;

- Consider common and unsafe workplace practices such as incorrect use of safeguards, bypassing of protective devices, removal of guards, or changes in the program of electronic programmable safety devices.

4. Storage space

Storage space around machinery can create hazardous situations. When large pile of material is placed next to the machine, this can create blind spots and result in accidents such as collision between forklifts and pedestrian. The material itself can be hazardous; e.g. a pile of metal sheets next to a hydraulic power press brake. Sheets have sharp corners, they are heavy and can harm personnel; i.e. harm to lower limbs and back pains when manually feeding or inserting sheets to machine. Moreover, feeding machine manually can create hazardous situations (Brauer, 2006):

- Analyse the type and quantities of materials that may be present;
- Plan storage location for each type of item;
- Allow for the separation of incompatible materials, such as oxidizers and fuels;
- Provide adequate storage equipment and racks to keep materials organized;
- Clearly mark all areas.

3.3.2 Movement

Safety should not be an afterthought when designing the material handling, machinery and equipment movement. Discussions on machineries and material handling safety from the perspective such as load, equipment, gang-way spaces and unnecessary movements are discussed under this dimension.

5. Material handling load, method and equipment

Statistics showed that lifting or handling operations result in a vast number of injuries to employees (UniversityCollegeLondon, 2000). Good lifting techniques save employees from back problems and should be used to ensure no unnecessary pain is suffered.

Cranes, pulleys, blocks, chain and wire or rope slings are used to handle heavy materials and equipment, which must not be used by untrained employees (UniversityCollegeLondon, 2000). Safe working loads will be clearly marked on equipment that regularly inspected and tested. Rules for picking up a load include (Goetsch, 2008):

– Make sure the load is within the capacity of the material handling machine;

– Make sure the load is properly balanced;

– Make sure the load is secure;

– Raise the load to the proper height.

Powered industrial truck or forklift safety can cause injuries which often result from impact or acceleration hazards. Forklifts are different from cars and trucks in several ways and employees should consider these differences (Goetsch, 2008).

– Consider that forklifts are typically steered by the rear wheels and an empty forklift can be more difficult to steer than one with a load;

– Consider that forklifts are frequently driven in reverse;

– Consider that forklifts have tree-point suspension so that the centre of gravity can move from the rear of the vehicle closer to the front when it is loaded.

– Consider that forklift overturn is frequent and that speed, loads, driving and loading techniques are causal agents for these accidents.

Because of these differences, it is important to ensure that only trained employees drive forklifts and they follow rules of lifting, travelling, and speed to prevent accidents.

6. Movement of machinery, machine part and equipment

In reviewing mechanical hazards of machinery and equipment, one should consider movements in machines which may have sufficient force to cause injuries (WorkSafe, 2007):

– Be aware of machinery and equipment with moving parts that can be reached by people;

– Be aware of machinery and equipment which can eject objects (parts, components, products or waste items) that may strike a person with sufficient force to cause harm;

– Be aware of machinery and equipment with moving parts that can reach people such as booms or mechanical appendages (arms);

– Be aware of mobile machinery and equipment such as forklifts, pallet jacks, earth moving equipment, operated in areas where people may gain access.

7. Minimum aisle width

Determining optimal aisle width is a critical part of an overall storage/material-handling strategy. Aisle width decisions must attempt to achieve the best combination of productivity, space utilization, flexibility, safety, and equipment costs for the specific application.

- Where mechanical handling equipment is used, sufficient clearances for the type and size of the equipment should be maintained, including sufficient aisle clearances;
- The powered industrial trucks require sufficient overhead clearance from pipes, lights, overhead installations, sprinklers, etc. This fact is based on the size and manoeuvrability of the material handling equipment.

3.3.3 Workforce & Ergonomics

Labour experience, training and flexibility of jobs could greatly impact the safety of workers. Furthermore, ergonomics approach will provide a better condition for workers to perform the tasks well.

8. Training, education and labour experience

Only qualified and certified personnel are permitted to undertake any hazardous duties or operations such as handling toxic, explosive or highly flammable materials in order to maintain, service, or repair any dangerous equipment or in order to transport and operate any vehicle, mobile equipment or its component assemblies (Goetsch, 2008).

Programs are instituted to qualify and certify workers for their duties. Qualified personnel are indicated as certified by suitable identification issued after proficiency examination and demonstration. Certification programs include training and testing on safety subjects such as hazard involve in the operation for which the worker is being certified, practices and procedures required to protect themselves and others, remedial actions to be taken in any contingency, safety devices, possible malfunction and marking of wiring, piping, and equipment, meaning of warnings, sound alerts or any other emergency signal, and any other information the safety manager considers advisable (Goetsch, 2008).

9. Self-inspection and personal protection

No person is required to perform an operation that could result in injury to himself or to any other person because of close proximity or incompatibility of their tasks. In order to (1) avoid injurious effects on the body and (2) safeguard workers in the event of accidents, managers must ensure that certain rules are observed (Goetsch, 2008):

- For normal operations, first choice is eliminating the hazard in the environment rather than using personal protective equipment;
- Approved protective equipment and devices must be made available and used to guard against specific hazards that cannot be eliminated but should be controlled when encountered during the operation;
- No supervisor should permit conducting an operation unless such equipment and devices are in proper working order and used as stipulated by the safety engineer;
- Only protective and rescue equipment approved for the purpose by responsible agencies and in accordance with OSHA or other mandatory standards should be used;
- Location of personal protective, emergency, and first aid equipment must be easily accessible and readily distinguishable;
- Equipment should be stored as close as practicable to the possible point of use. Operating procedures should identify the equipment stored and its location. Inspections are to be made periodically to ensure that stipulated items are present;
- No person should enter a hazardous environment without the prescribed protective equipment, remove it while in the hazardous environment, or use it if it is faulty or damaged. Tests to demonstrate the equipment is operating properly are required before a worker enters a questionable environment;
- All workers must be familiar with the capabilities, limitations, and proper method of fitting, testing, using, and caring for protective equipment. Managers will require and ensure that courses of instruction are provided to familiarized personnel with safety equipment. Safety engineers and supervisors will schedule practice sessions or have training units conduct sessions to maintain user proficiency;

– Devices are available to detect, warn, and protect against an impending or existing adverse environmental condition. Such equipment should be used to evaluate atmospheres that might be toxic, flammable, or explosive or in which excessive levels of radiation, heat, pressure, noise, or other hazard might exit. Devices will be provided to apprise personnel of the status of such conditions that might be hazardous or of the loss of control of a hazard. Equipment provided should be adequate for detecting the presence of the hazard under conditions other than normal for the operating environment;

– Detection and warning equipment should be maintained in a state in which operations and readings are dependable and accurate; which should be tested and calibrated periodically;

– Detection and warning equipment should be installed, maintained, adjusted, and repaired only by trained personnel.

10. Job flexibility

Flexible work arrangements are alternate arrangements from the traditional working day/week. Employees may choose a different work schedule to meet personal or family needs. Alternatively, employers may initiate various schedules to meet their customer needs. Job flexibility is a critical resource for maintaining job satisfaction and quality of life among employees. Many benefits are reported by various studies (CCOHS, 2002):

– Increased ability to attract, retain and motivate high-performing and experienced employees;

– Reduced absenteeism;

– Helps employees manage their responsibilities outside of work;

– Increased job satisfaction, energy, creativity and ability to handle stress.

Flexible job can be distinct as:

Flex-time: A work schedule with variable starting and ending times, within limits set by one's supervisor/manager. Employees still work the same number of scheduled hours as they would under a traditional arrangement (MIT, 2004).

Job-sharing: An arrangement in which two or more part-time employees share the responsibilities of one full-time job (MIT, 2004). This way, the tasks performed by employees would be more variable; as well as the increase in the number of machines operated by a workforce. However confusions might be caused from several operations carried out simultaneously.

11. Safe Access to machineries

People may continually or occasionally access machinery and equipment for tasks such as operation, maintenance, repair, installation, service or cleaning. Therefore, safe access must be provided suitable for the work performed in, on and around them. A stable work platform suited to the nature of the work, allowing good posture relative to the work performed, sure footing, safe environment and fall prevention are basic requirements. Access needs can be predicted and planned in advance. Access may vary during each stage of machinery and equipment life cycle (WorkSafe, 2007):

- *Installation or removal:* complete access from every area is required and involves disconnection or connection of services such water, air, pipes, installation of electrical cable to switch board, etc.;
- *Operation:* access for set-up, operation and adjustment;
- *Maintenance, repair, cleaning, alteration or adaptation:* access to remote areas is required.

12. Ergonomic hazards

Ergonomic hazard is a physical factor that harms the musculoskeletal system. It includes uncomfortable workstation height and poor body positioning. Ergonomic injuries include strains, sprains, and other problems. These injuries can be caused by: performing the same motion over and over again (such as vacuuming); using physical force (lifting heavy objects); or being in an awkward position (twisting the body to reach a light bulb). The four main ergonomic hazard factors are force, posture, repetition and duration (OFSWA, 2007):

- Force is generated by muscles to lift, lower, push, pull or hold objects. There is the risk of injury when the amount of force required for a job is more than the muscles can handle;
- Posture is the position of the different parts of the body related to one another. The more extreme, awkward or unnatural the posture, the greater the risk of injury to the muscles, ligaments, tendons and nerves;

- Repetition is the number of times an action or body motion is performed over a given time period. Jobs that require repetitive motion increase the stress to the muscles and tendons because of fatigue;
- Duration is the length of time an activity or movement is performed, a posture is held or a worker is exposed to other ergonomic hazards such as force or repetition. Even though a movement or activity may be fairly comfortable, the duration of job over a long period can lead to injury.

Other ergonomic hazard factors include: contact stress, vibration, temperature, work organization and methods.

3.3.4 Maintenance & Services

Accessibility and distances among machines, as well as the maintenance services concerned this safety factor.

13. Access to machines for setting, maintenance or repair

Employees can safely service or maintain machines with a guard in place. For example, polycarbonate and wire-mesh guards provide great visibility and can be used to allow maintenance employees to safely observe system components. In other instances, employees may safely access machine areas, without locking or tagging out, to perform maintenance work (such as machine cleaning or oiling tasks) because the hazardous machine components remain effectively guarded (OSHA, 2007); whereas the followings need to be taken into account:

- When considering the suitability of distance guarding, also should be considered the safe access requirements of maintenance people who gain access by ladder, scaffold or elevated work platform;
- Consider the sufficient space for maintenance or emergency operation;
- Consider adequate space area for critical maintenance and auxiliary services during the operation;
- Maintenance workers should lock out the machine from its power sources before beginning the repair;

- When several maintenance persons work on the same machine, multiple lockout devices should be used;
- The maintenance equipment itself should be properly guarded;
- The use of plant rooms, electrical switch rooms and other service areas such as service ducts, roof spaces and flat roofs, should be strictly limited to the purpose for which they were designed. Entrances to such areas must be kept locked and notices displayed indicating that unauthorised persons shall not enter.

14. Machine safeguards flexibility and machine-guard removal

A guard can perform several functions: it can deny bodily access, contain ejected parts, tools, off-cuts or swath, prevent emissions escaping or form part of a safe working platform. An effective guard or safety device must have certain features and meet certain criteria (Goetsch, 2008):

- Machines must be safe under all conditions. If it fails, causes to operate, or is opened, the machine should immediately and automatically stop;
- Access to the danger zone must be prevented while the equipment is operating;
- It must impose no restriction, discomforts, or difficulties for the worker;
- It must automatically move into or be fixed into place;
- It must be designed for the hazard, the machine, and type of operation;
- It must not require delicate adjustment for use or move out of alignment easily;
- It must be difficult for an operator to bypass or inactivate it without simultaneously inactivating the equipment on which it is mounted;
- It should require minimum maintenance;
- It should not itself constitute a hazard.

Guarding is commonly used with machinery and equipment to prevent access to (WorkSafe, 2007):

- Rotating end drums of belt conveyors;
- Moving augers of auger conveyors;

- Rotating shafts;
- Moving parts that do not require regular adjustment;
- Machine transmissions, such as pulley and belt drives, chain drives, exposed drive gears;
- Any dangerous moving parts, machines or equipment.

3.3.5 Material

The type and characteristics of the products and material used in the manufacturing process is an important dimension of safety to be considered.

15. Characteristics of product

Factors such as size, shape, volume, weight, etc. of the materials and products can influence the safety considerations. The material/product and its components, including physical, chemical and environmental characteristics, and toxicity information, should be evaluated and assessed to determine the potential physical (fire and reactivity), health and environmental hazards associated with the material. Using professional judgement, the product should be classified according to the hazard criteria specified in legislation of the country where the product will be used; e.g., classify chemical products as flammable versus combustible or toxic versus very toxic.

3.3.6 Environment

Work environment is an important issue to consider. The environment should provide proper illumination, noise control, ventilation and temperature in order to accommodate the employees. Thus, work environment determination has to be carried and considered during the facilities planning process in order to achieve a higher production performance.

16. Noise disturbance

Legislation makes loss of hearing linked to the workplace compensable. Both employers and employees are therefore obliged to observe existing noise standards. Engineering solutions range from the use of component parts generating less noise, use of enclosures around machines to reduce noise level, to personal protective equipment (PPE) (e.g., ear plugs). High noise level can interfere with communication among workers, induce stress and result in accidents. Employees need to be trained to (Goetsch, 2008):

- Understand the danger to hearing that comes from prolonged and high level of noise exposure;
- Recognize noise exposures which are harmful;
- Evaluate noise levels of exposure in a practical way;
- Take action to protect from harm of noise.

17. Electricity or released of stored energy

The use of electricity and electrical equipment are so common that most persons fail to appreciate the hazards involved. These hazards can be divided into five categories: (1) shock to personnel, (2) ignition of combustible or explosive materials, (3) overheating and damage to equipment or burns to personnel, (4) electrical explosions, and (5) inadvertent activation of equipment (Goetsch, 2008).

Interlocks: Where an enclosure is breached, the circuit will be broken automatically and the system will be de-energized. Because enclosures are frequently opened for maintenance purposes, during which circuits must be checked, interlock switches must be operable deliberately when the access panel is open. Such switches should be of a type which reinstitutes the safety function when the enclosure is closed again (Goetsch, 2008).

Insulation: Insulation parts of electrical equipment which a person will contact routinely or accidentally during operation of the system are advisable. Insulated knobs, dials, handles and buttons on controls, switches, drawers, and meters are such items. Rheostats and potentiometer control shafts can be coupled to nonconductive rods and knobs (Goetsch, 2008).

Isolation: Electrical equipment, especially high-voltage type, should be isolated to keep unauthorized personnel from approaching too close. Large transformers with exposed terminals can be located in vaults or fenced enclosures to which only authorized persons have access. Panel boards, generators, large motors, batteries, bus bars, and other electrical equipment which might be hazardous should be enclosed or provided with guards to prevent accidental contacts (Goetsch, 2008).

Marking device: A suitable warning device may be connected to electrical equipment to indicate when it is energized. This may be a light, steady or flashing; a suitably coloured indicator; an on-off sign; or an audible signal (Goetsch, 2008).

18. Temperature and pressure, radiation, fire and explosion

High and low temperatures, heat, cold, and the variations can be directly injurious to personnel and damaging to equipment. Effects can be generated, e.g., by thermal changes in the environment which lead to accidents and therefore indirectly to injuries/damage. Numerous investigators have studied the effects of temperature on performance. In almost all instances, there is agreement that stresses generated by high temperatures degrade performance. The effects of heat will depend on the following factors: intensity of the heat, duration of the exposure period, tasks involved, persons performing the tasks, presence of other stresses (Goetsch, 2008).

One of the worst effects of elevated temperatures is the increased susceptibility to fire. If the temperature is high enough or the volatiles in the organic material are reactive, a fire may start spontaneously. Thermal radiation from flames, molten metal, or other high-temperature source can cause charring of materials such as wood, paper, and cloth. Charring can also occur when such material is in contact with a high temperature source such as a steam line, hot electronic equipment, or an overheated bearing (Goetsch, 2008).

Radiation may be either a direct or indirect source of fire ignition. Sunlight can be concentrated intentionally or accidentally by a lens or curved reflectors to cause ignition of combustible materials. Solar reflectors provide some of the highest temperatures available without the use of nuclear devices. Less efficient concentration of solar energy may still constitute sources strong enough to cause fires. Flames, industrial heating furnaces, highly incandescent metals, and glowing solid combustibles can also radiate energy to ignite flammable materials. Lasers can generate beams whose intensities may cause combustibles to ignite (Goetsch, 2008).

19. Illumination

Lack of lighting can contribute to accidents. People need to see what they are doing and where they are going. Some aspects of lighting are distracting or interfere with tasks. The major hazards associated with lighting involve illumination levels, changes in illumination levels, qualitative aspects of lighting and flicker of some light sources (Brauer, 2006).

Confined spaces generally have poor lighting, where temporary lighting is often needed. In potentially explosive atmospheres, lighting designed for such situations should be used.

20. Respiratory hazards

Respiratory hazards can be present as: gases, vapours, fumes, mist, and dusts. A variety of equipment can be used to protect workers from respiratory hazards. Devices range from simple, inexpensive dust masks to sophisticated self-contained breathing apparatus; i.e., air-purifying respirators and supplied-air respirators.

Ventilation is an effective method of controlling respiratory hazards. The space can be purged of dangerous atmospheres by blowing enough fresh air in, and/or by removing (or suction venting) the bad air and allowing clean air in. The best results are obtained by blowing fresh air into a space close to the bottom. Check the efficiency of ventilation by re-testing the atmosphere with the gas detection equipment before entry.

When ventilation is used to improve the air in a confined space, ensure that the toxic or flammable gases or vapours removed from the space do not pose a risk to other workers. Exhaust air should not be discharged into another work area.

3.4 Conclusion

Over the years it has been found that numerous problems can be avoided in designing or modifying plants if facilities plans are reviewed for safety aspects before initiating any construction or change. Furthermore, facility managers are the most responsible professionals for integrating people with their physical environment. As such, they often find themselves facing a myriad of complexities and challenges. Each of these challenges requires greater effort on the part of employers in identifying, correcting and preventing safety and health hazards. The key to reducing safety and health hazards is an effective safety management program.

However, the injury frequency or severity rates which are extensively used by government agencies for measuring occupational injuries/death, only reflects the status of the occupational safety and neither provide the management of any information for improvement. To effectively manage the safety management system, a composite performance evaluation system consisting of measurable and achievable indicators in many facets of safety management is definitely required.

Nevertheless, there is no general outline for an inherently safer process. One problem is how to minimize simultaneously the risk associated with all of the process hazards. In the real world, the various hazards are not independent of each other, but are inextricably linked together (Hendershot, 1995). A process modification, which reduces one hazard, might impact on the risk resulting from another hazard.

On the basis of previous research on safety management and the guidelines developed by international bodies and empirical studies on the safety features, as well as the importance of reviewing the safety aspects in the early stages of facilities planning, the authors considered that the safety management system is a multi-dimensional construct made up of the following factors: (1) safety policies reflecting the hazards caused by machineries and equipment; (2) safety in designing the material handling system, machinery and equipment movement; (3) employees training, experience and flexibility of jobs; (4) safety in maintenance and services; (5) type and characteristics of the products and material used in the manufacturing process; and (6) environmental aspects of safety.

A comprehensive list of safety criteria was developed, discussing different aspects of the six above mentioned factors. Facilities planners can use these criteria to evaluate their situation in regards to safety management, and to guide them about which areas they must improve if they wish to reduce their accident rates and losses.

Future research will focus on appraising the specific safety criteria and their importance for different type of plant layouts. While the presented guideline can be presented as a safety audit checklist for the facilities planners, different facilities layout planning tools can be modified to acknowledge a more detailed consideration of safety.

Moreover, the research can be enriched by quantitative information, such as performance indicators (related to the given criteria) which will be optimized by the best practices listed in this paper.

CHAPTER 4 ARTICLE 1: A PROPOSED OCCUPATIONAL HEALTH AND SAFETY RISK ESTIMATION TOOL FOR MANUFACTURING SYSTEMS

Abstract[2]

There are numerous hazards to be found in almost any workplace. Annually, millions of workers die, are injured, or become ill as a result of these occupational hazards. Industrial machines are often involved in these occupational accidents. Because of the demands of regulatory compliance, and the potentially high cost in terms of human suffering and lost production, businesses should place particular emphasis on safety measures. Risk is defined as a combination of the probability of harm and the severity of its consequences. Generally, risk estimation involves examining the hazards associated with a situation or with the use of a machine. A large number of techniques have been proposed for risk estimation and recent studies have revealed that some of them have serious flaws.

The main objective of this paper is to develop a proposed risk assessment tool based on the findings of an earlier study. Our research results constitute a first step towards the integration of occupational health and safety (OHS) concerns into facility planning models which traditionally do not consider OHS. The proposed risk estimation tool is developed based on the characteristics, strengths, and weaknesses of 31 existing risk estimation tools, and is then applied to 20 scenarios representing different hazardous situations. To evaluate the performance of the proposed tool, the results were compared with those of other risk estimation tools and confirmed its proposed ability to estimate risk relative to other risk estimation tools.

Keywords: occupational health and safety (OHS), risk estimation tools, manufacturing systems.

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4.1 Introduction

Competition in the global marketplace has driven improvements in production systems in the manufacturing companies, and these improvements steer performance factors, including production capacity, work in process and cost efficiency (Neumannr et al., 2002). It remains the case, however, that the manufacturing industry is one of the most dangerous sectors for workers, given the frequency and severity of occupational accidents (Silvestri et al., 2012). As a result, health and safety at work is one of the most important areas for targeted action in social policy, in both the European Union and the USA. Work-related injuries can compromise industrial competitiveness (Arne, 1994; Hendrick, 1996), owing to the costs related to labour turnover, absenteeism, and spoiled and defective goods, all of which reduce productivity (Andersson, 1992). Also, the quality of the work of employees is strongly related to the level of concern for occupational health and safety (OHS) issues in the manufacturing context, i.e. in terms of employee performance and the efficiency of work systems (Erdinc and Yeow, 2011). OHS contributes to product conformity by ensuring that the conditions necessary for thoroughly carrying out tasks are met (De Oliveira Matias and Coelho, 2002). The Occupational Safety and Health Administration, the European Committee for Standards and the International Organisation for Standardisation (ISO) define recommended limits of exposure to some hazards in the workplace to reduce work-related injuries, and set out the responsibilities organisations have to protect the health and safety of their employees (Mutlu and Ozgormus, 2012). Protective action in the form of design changes, the use of safeguards and the implementation of safe procedures in the workplace will substantially reduce the probability of occurrence of harm and the severity of harm. Risk is the means for collecting and evaluating data on severity of an injury or probability of harm occurring in the workplace and an important tool for managers to use to analyse the potential impacts of any risks identified in the organisation (Lee et al., 2013).

Ideally, a facility layout should be designed to be efficient over time (Krishnan et al., 2009) and to ensure employee OHS. The physical arrangement of the components of the facility layout, referred to as the ‘shop floor’, includes the assignment of departments, machines and equipment to the most appropriate locations in the workspace to allow greater efficiency (Deb and Bhattacharyya, 2003). A physical arrangement, which minimises the movement of personnel and material between departments, could decrease material handling costs, increase system effectiveness and productivity and enhance safety by reducing the risks associated with production activities. In practice, many more factors need to be considered in addition to monetary costs, an important one, being the maintenance of a safe and pleasant environment for the employees (Tompkins, 2010).

The relationship between facility layout design and OHS has not been researched extensively. Chang and Liang (2009) developed a model based on a three-level multi-attribute value approach to evaluate the performance of process safety management systems at paint manufacturing facilities. Fernandez-Muniz et al. (2007) developed a Safety Measurement System Scale based on the results of a survey of 455 Spanish companies to be used as a guide for managing the safety activities of organisations. Much earlier, Penteado and Ciric (1996) had presented a mixed-integer non-linear approach to optimising process plant layout which integrates safety and economics. Their approach identifies safe and economical layouts designed to minimise the overall cost of operating a chemical plant. Broberg (2007) refers to the concept of workspace design as a potentially new approach for ergonomists and other OHS consultants to consider. In the 1990s, Hinze and Wiegand (1992) had investigated whether or not designers were concerned with the safety of construction workers in their survey of major US design firms conducted to determine the extent to which design decisions are made, with specific emphasis on the safety of these workers. Shikdar and Sawaqed (2003) identify factors that affect worker productivity and OHS. It can be concluded from these studies that facility planners lack a tool for integrating OHS into models as one of the variables to optimise in addition to the traditional elements. It is also the case that OHS is basically a qualitative measure and cannot be included in facility planning models directly, unless safety issues can be quantitatively measured and compared with other important variables, such as cost. The main focus of this research is on introducing a scheme for quantifying OHS.

Specifically, this study is aimed at developing a risk estimation tool for OHS in a manufacturing company. The research methodology is based on a sample of risk estimation tools that have been devised in a previous study (discussed in Section 4.2.3), comparing their characteristics and then identifying the parameters that must be included in a proposed tool. In addition, risk scenarios that were developed in the study discussed in Section 4.2.3 were evaluated, using the proposed tool, and the results were compared with those of other risk estimation tools.

The outcome of this research is a risk estimation tool that includes some of the desirable traits in terms of architecture and parameters. The tool calculates a risk value using a numerical approach, which is believed to facilitate the integration of OHS into facility planning models. OHS will be one of the inputs to these facility planning models along with costs and space constraints.

4.2 Risk Estimation in Machine Safety

Generally, improving workplace safety begins with a risk assessment, which consists of a series of steps to examine potential hazards. The process includes a risk analysis, followed by risk estimation. ISO 12100 describes risk analysis as comprising three stages: determining limitations, identifying hazards and estimating risk.

Methods for identifying hazards and estimating risk take many forms. Wassell (2008) presents a coherent and concise description of current methods for risk identification, and describes their limitations. Etherton (2007) reviews risk assessment concepts and methods which involve linking current risk theory to machine risk assessment, as well as exploration of how various risk estimation tools translate into decisions on industrial machine design and use. Anderson (2005) explores the risk analysis techniques applied during the design and use of industrial machines. The report by Parry (1986) describes the underlying principles and philosophy of hazard identification techniques, and discusses their use and limitations. In it, he reviews various techniques that are available for identifying hazards associated with the processing, storage and handling of dangerous substances, namely: HAZOP, checklists, FMEA, Fault Tree Analysis, Event Tree Analysis and Cause-Consequence Analysis.

4.2.1 Risk Estimation Tools

As noted by Main (2004b), Worsell and Wilday (1997) and Worsell and Ioannides (2000), although many tools and methods have been proposed for estimating risk in companies, it is not easy to choose the tool that is best adapted to a particular company’s needs. Risk estimation tools make it possible to qualify or quantify the risks inherent in various hazardous situations, in order to quickly distinguish high-risk situations from low-risk ones Etherton (2007). These tools can be classified according to a number of criteria. The most notable aspects are addressed in Chinniah et al. (2011) as: diversity in the nature of each risk estimation tool; how to describe and define each parameter; the number of parameters; how to calculate, quantify and qualify risk; how to classify or evaluate the final result, etc.

Qualitative tools use at least two parameters. The severity of harm is represented, as is the probability of occurrence of harm. It is important to recognise that even traditional safety analyses must deal with the frequency of occurrence of harm, although these probabilities are not quantified, as they are in quantitative risk estimation. The outputs of risk estimation tools are relative rather than absolute, and so risks estimated using one tool cannot be directly compared to those estimated using another tool (ISO/TR14121-2, 2012).

The majority of qualitative risk estimation tools are either risk matrices or risk graphs. A risk matrix is a multidimensional table in which any class of severity of harm can be combined with any class of probability of occurrence of harm (Clemens, 2000). Numerous research studies have used a risk matrix structure to introduce their risk estimation tools; e.g. BT, Kazer, Raafat Matrix and Wells SCRAM presented in Worsell and Wilday (1997); and US CPSC, HSE Construction and Australia Environment presented in Main (2004b).

A risk graph has a tree structure, configured from left to right (ANSI/RIA.R15.06, 1999). Two examples of applying the risk graph structure in risk estimation tools are the MEP risk graph (Worsell and Wilday, 1997) and the risk graph used by the CSST (Occupational Health and Safety Commission) in Quebec, Canada (2006).

Quantitative risk estimation tools can be thought of as numerical scoring tools and quantified risk assessment. Quantified risk estimation tools calculate the probability of a specific outcome occurring during a specific period of time (Etherton, 2007). Numerical scoring tools have between two and four parameters which are broken down into a number of classes, similar to risk matrices and risk graphs. However, instead of a qualitative term, a numerical value is associated with a class (Manuele, 2001). One application of numerical scoring tool is the SUVA risk assessment method presented by Bollier and Meyer (2002).

4.2.2 Risk Estimation Parameters

Differences in the number of parameters, the types of parameters, the number of levels, and the definitions of the parameters contribute significantly to the variations found in risk estimation tools.

In ISO/IEC Guide 51:2005, risk is interpreted as comprising two parameters, severity and probability, and these form the basis for the risk estimation techniques that are popular for evaluating workplace risks (ISO/IEC-Guide51, 2005). ISO 12100:2010 states that the probability of occurrence of harm is itself made up of a number of parameters. These are the frequency and duration of exposure, the probability of occurrence of a hazardous event, and the possibility of avoiding or limiting the harm that results (ISO12100, 2010).

1. The severity of harm can be estimated by taking into account:

- the severity of injuries or damage to health; e.g. slight, serious, or fatal,
- the extent of harm; e.g. to one person or to several people,

2. Probability of occurrence of harm can be estimated by taking into account:

    a) Nature of the exposure of people to the hazard:

    - reason to access the hazard zone, e.g. for normal operation, correction of a malfunction, maintenance, or repair,
    - nature of access; e.g. manual feeding of materials,
    - time spent in the hazard zone,
    - number of people requiring access,
    - frequency of access.

    b) Occurrence of a hazardous event:

    - reliability of statistical data,
    - accident history,
    - history of harm to health,
    - risk comparison.

    c) Technical and human possibility of avoiding or limiting the harm:

    - the people involved i.e. who may have been exposed to the hazard (skilled or unskilled workers),

- how quickly the hazardous situation could lead to harm, e.g. suddenly, quickly, or slowly,
- awareness of risk, e.g. generally available information, user manuals, direct observation, warning signs, and warning devices on the machinery,
- the human capacity to avoid or limit harm, e.g. reflexes, agility, possibility of escape,
- practical experience and knowledge, e.g. knowledge of the machinery or of similar machinery, or the absence of experience or knowledge.

The risk assessor is required to select the probability of occurrence of harm and the severity of harm from a fixed number of levels. There are generally three or four levels for each parameter (Charlwood et al., 2004). Chinniah et al. (2011) define equivalence scales for the parameters in risk estimation tools, as well as including their risk levels. Their definitions are used in this paper, and further explained in section 4.5.2.1.

4.2.3 Comparison of Risk Estimation Tools Involving Machinery

Since the information presented in the research by Chinniah et al. (2011) is extensively used in this paper, a summary of their research is provided here.

In Chinniah et al. (2011), the authors study 31 risk estimation tools which follow the ISO 12100:2010 guideline for estimating the risks associated with industrial machinery. They do so by comparing the risk estimation parameters as well as by applying various tools to estimate the risks associated with 20 hazardous scenarios. The study theoretically compares the performances of these tools in estimating risks, and evaluates whether or not the tools estimate risk uniformly.

The 20 scenarios depict a number of real life hazardous situations that could occur in different industries and with different perceived risk levels. A list of these scenarios is presented in Appendix B.

The results show significant differences among the tools in terms of estimating the risks associated with the same hazardous situations, i.e. risk is tool-dependent. The scope of the tool and its construction, or architecture, seems to be one of the contributing factors in the variability of the results. Tools that follow the two configurations proposed in ISO 12100:2010 produce similar average risk levels, but tools in both configurations will underestimate or overestimate the risk associated with hazardous situations. They also observe that the 31 estimation tools could be classified into three groups: 9 low risk estimating tools, 8 intermediate risk estimating tools and 14 high risk estimating tools. Moreover, there are tools that are not appropriate for risk estimation involving machinery, even though it is often claimed that they are. The authors propose a series of construction rules for the tools, in order to alleviate most of the problems associated with the variability in the risk estimations (Chinniah et al., 2011). The 31 risk estimation tools and the 20 hazardous scenarios are used in this study.

4.3 Research Objective

Risk estimation can be carried out using a wide variety of tools, depending mainly on the nature of the hazards and on user preference. However, previous research has revealed that many risk estimation tools contain flaws which can be biased towards high or low risk estimates, which, if they are systematic, can lead to incorrect prioritization of risk reduction activities or inappropriate risk reduction measures. Some variability in the risk estimation process can be expected, but a wide discrepancy in the results may lead to loss of credibility in the process.

4.3.1 Research contributions

The new risk estimation tool is based on the findings of previous research, and is designed for integration into facility planning models. The integration stage will be addressed in future research. The proposed risk estimation tool quantifies OHS, and its output is a suitable input for a facility planning model with other inputs, such as cost and space constraints.

In this paper, the proposed risk estimation tool is described, and its results compared with that of other risk tools.

4.4 Research Methodology

This paper focuses on presenting a risk estimation tool that can be used for estimating risk. The overall research methodology is as follows:

1. Use previous studies on risk estimation tools as the starting point.

2. Apply the desirable traits of these tools, in terms of the number of risk parameter levels and definitions.
3. Study numerical tools (5 out of 31) suitable for designing an equation for calculating the risk value.
4. Test the proposed tool by applying it to 20 hazardous scenarios.
5. Evaluate the proposed tool by verifying how it performs compared to other tools, based on the average results for each scenario with the application of the 31 tools, i.e. rank the scenarios from lowest to highest risk, using the ranks established in the previous study.

4.5 The Proposed Risk Estimation Tool

In this section, the phases for developing the proposed risk estimation tool are discussed.

4.5.1 Equation-based Risk estimation Tools

Various risk estimation tools were studied to identify their characteristics, such as the risk parameters, the number of risk levels, the equations, and the approaches they follow to assess risk. These tools were mainly adapted from Chinniah et al. (2011) and Gauthier et al. (2012), in which the authors analysed 31 qualitative and quantitative tools.

The 31 tools were studied in detail and that number was narrowed down to five tools that calculate risk, as presented in Table 4.1.

The five tools introduced in Table 4.1 are not the only risk estimation tools available to estimate risk; however, they are well-known tools that calculate risk using an equation.

4.5.2 Proposed Risk Estimation Tool

The proposed risk estimation tool uses the severity (S) of harm and the probability of occurrence of harm (Ph), the latter comprising:

- Frequency of exposure to the hazard (Exf).
- Duration of exposure to the hazard (Exd).
- Probability of occurrence of a hazardous event (Pe).
- Technical and human possibility of avoiding or limiting the harm (A).

Table 4.1: Summary of the five risk estimation tools selected

Tool	Parameters (# of levels)	Risk calculation equation
BT (Worsell and Ioannides, 2000)	- Potential to cause harm (3) - Likelihood of causing harm (3)	Risk = Hazard * Likelihood
Company A	- Severity (3) - Probability of occurrence of a hazardous event (3) - Frequency of exposure to a hazard (3)	Risk = Severity + Probability + Frequency
SUVA (Bollier and Meyer, 2002)	- Severity (5) - Probability of occurrence of harm (5) - Frequency and duration of exposure to a hazard (5) - Probability of occurrence of a hazardous event (5) - Technical/human possibility of avoiding/limiting harm (3)	Risk ~ F (Severity; Probability of harm) Probability of harm = Frequency and duration + 2* Probability of hazardous event + Avoidance
NORDIC (Mortensen, 1998)	- Severity (4) - Probability of occurrence of harm (4) - Frequency of exposure to a hazard (5) - Probability of occurrence of a hazardous event (5) - Technical/human possibility of avoiding/limiting harm (3)	Risk ~ F (Severity ; Probability of harm) Probability of harm = Frequency + Probability of hazardous event + Avoidance
Gondar (GondarDesign, 2000)	- Severity (3) - Probability of occurrence of harm (3)	Risk = Severity * Probability of harm

In the literature, frequency and duration are often combined into one risk parameter: the exposure of people to the hazard (e.g., ANSI /RIA-R15.06 (1999); ISO14121 (2004); Mortensen (1998)). This research is based on four-parameter categorization for Ph.

Definition of the Proposed Risk Estimation Model

The proposed risk estimation model was based on the identified parameters. The mathematical relations between the parameters, as well as the weight assigned to each of them, have been adjusted according to the approach taken in the five selected tools. The equation was developed as follows:

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

The proposed equation is a combination of the approaches described above. It includes all the risk parameters highlighted in ISO 12100, and is used to calculate the risk value for each scenario. Risk is calculated by multiplying the qualitative value of S by the qualitative value of Ph. This function is similar to the approach used in the BT and Gondar tools.

To calculate a numerical value of the probability of occurrence of harm (Ph), an approach similar to that applied in SUVA, NORDIC, and Company A was used. Four parameters are added: frequency of exposure to the hazard (Exf), duration of exposure to the hazard (Exd), probability of occurrence of a hazardous event (Pe), and possibility of avoidance (A). In this function, the weight for the Pe value is considered to be twice that of the other parameters. This is because the likelihood of occurrence of a hazardous event, which may be of a technical nature (e.g. system reliability) or caused by a person (e.g. error, fatigue), has a higher rank than the other parameters (Bollier and Meyer, 2002).

4.5.2.1 Proposed Risk Estimation Parameters and Levels

Since the proposed risk parameters are qualitatively scaled, so that they can be transformed into quantitative measures, a rating system is used by which quantitative values are assigned to the levels of each risk parameter. These values are based on a numerical rating scale of 1 to 5, where 1 is the lowest risk and 5 is the highest importance of risk. The number of levels for each parameter is determined from the equivalence scales which were formed by considering all 31 tools and matching their individual levels against one another, as explained in Chinniah et al. (2011). It is believed that the proposed tool will effectively discriminate among the various parameter levels and offer the desirable granularity if its five risk estimating parameters have a similar number of levels, as identified in Chinniah et al. (2011). These parameters, their risk levels, and the corresponding quantitative values are presented below.

1) Severity of harm (S)

The severity of harm parameter is defined as a hazard with the potential to cause harm. The likely effect of a hazard can be rated as in Table 4.2.

Table 4.2: Severity of harm

Severity of harm (S)	Rank
Slight injuries (bruises) requiring no first aid or injuries requiring first aid but without lost time	1
Injuries requiring more than first aid (assistance) and with lost time or when there is irreversible harm and slight disability, but the employee is able to return to the same job	2
Serious disability, the employee being able to return to work, but perhaps not to the same job	3
Permanent disability, and the employee can no longer work	4
One or more deaths	5

2) Probability of occurrence of harm (Ph)

Ph is estimated by four parameters. These parameters and their risk levels are listed in Table 4.3 – 4-6.

A. Frequency of exposure to the hazard (Exf)

Table 4.3: Frequency of exposure to the hazard

Frequency of exposure to the hazard (Exf)	Rank
Less than once per year	1
Annually	2
Monthly	3
Weekly	4
Daily to continuously, i.e. several times per hour	5

B. Duration of exposure to the hazard (Exd)

Table 4.4: Duration of exposure to the hazard

Duration of exposure to the hazard (Exd)	Rank
< 1/20 of work time	1
1/10 of work time (45 min per 8 hour shift)	2
1/5 of work time (90 min per 8 hour shift)	3
Half of work time (1/2) (4 hours per 8 hour shift)	4
Continuously during work time	5

C. Probability of occurrence of a hazardous event (Pe)

Table 4.5: Probability of occurrence of a hazardous event

Probability of occurrence of a hazardous event(Pe)	**Rank**
Negligible	1
Unlikely	2
Possible	3
Likely	4
Significant	5

D. Technical and human possibility of avoiding or limiting the harm (A)

Table 4.6: Technical and human possibility of avoiding or limiting the harm

Technical and human possibility of avoiding or limiting the harm (A)	**Rank**
Highly significant	1
Significant	2
Somewhat likely, with some conditions	3
Unlikely	4
Nil	5

These are the parameters that were used to model the proposed risk estimation tool. The quantitative values assigned to the risk levels make it possible to calculate a risk value, after which it is a simple matter to evaluate the risk inherent in the scenarios.

4.5.2.2 Proposed Risk Estimation Model

The steps outlined below should be followed for each hazardous scenario to determine the phases required to evaluate OHS in a company using the proposed risk estimation tool. This model will not only identify OHS deficiencies, but also guide facility planners when designing a new layout.

Step 1: Identify the qualitative risk level for each of the five risk parameters.

Step 2: Assign a quantitative value (1-5) corresponding to the risk levels identified in Step 1.

Step 3: Calculate the risk values:

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

4.6 Validation of the Risk Estimation Tool

The proposed risk estimation tool is applied to the 20 hazardous scenarios, in order to compare the risk values obtained with those attained from other risk assessment tools for the same hazardous scenarios. Figure 4-1 shows an example of one of these scenarios.

Scenario R **Thermal Hazard**	
Activity	Cutting out thermo-formed panel.
Hazard	Elevated temperature of cut panel (60 °C).
Hazardous situation	Worker in the proximity of the panel.
Hazardous event **(choose and define one specific hazardous event)**	Worker is in extended contact with the panel.
Probability of occurrence of hazardous event (considering training, experience, reliability of safety and non safety components, safeguards, supervision, defeating of safety devices, procedures…)	The worker is experienced in undertaking this task. The cuts and the tools necessary for this task need to be as close as possible to the panel and done while the panel is still hot.
Possible harm	Recurrent light burns.
Exposure information	On average 5 hours a day during an 8 hour shift.
Avoidance information **(considering information on time and speed, warnings, escape route, training, experience, …)**	The worker is experienced and aware of the danger. The nature of the work makes it difficult to avoid the contact with the hot panel. The worker is not wearing protective gloves.

Figure 4-1: Example of a hazardous scenario – from Chinniah et al. (2011)

In the analysis by Chinniah et al. (2011), the average risk for each scenario was computed. Then, the scenarios were classified in terms of risk level from low to high (A to T), according to the average of risk values obtained from the 31 risk estimation tools.

The following sections discuss how the tool proposed in this research would assess the risk associated with the scenarios, and where it stands compared to the other risk estimation tools. This analysis and comparison was conducted by the authors of this paper.

4.6.1 Estimating Risk for Scenarios

The 20 risk scenarios were evaluated using the proposed tool (Figure 4-2). For each scenario, the qualitative values of S, Exf, Exd, Pe, and A were determined. Then, the corresponding quantitative values were found, and a risk value was calculated for each scenario using the following equation: R=S*(Exf+Exd+2*Pe+A). Figure 4-2 shows these analyses. Applying this tool, the overall average risk for the scenarios is 38.9%, with a standard deviation of 23.3.

	S	Ph				Risk Value
SCENARIOS		**Exf**	**Exd**	**Pe**	**A**	**R=S*(Exf+Exd+2*Pe+A)**
S	5	5	1	1	4	**60**
G	2	5	1	3	1	**26**
A	1	5	1	4	3	**17**
B	2	5	1	2	2	**24**
R	2	5	5	5	4	**48**
N	3	4	1	4	3	**48**
O	5	4	1	1	2	**45**
E	2	3	1	1	3	**18**
H	1	5	1	5	5	**21**
M	4	4	1	2	2	**44**
K	3	3	2	1	3	**30**
L	5	3	1	2	3	**55**
I	2	5	3	2	1	**26**
P	2	5	5	4	4	**44**
J	3	5	5	2	1	**45**
F	1	5	3	2	5	**17**
C	1	5	5	1	2	**14**
D	1	5	5	5	4	**24**
T	5	5	5	4	5	**115**
Q	3	5	3	4	3	**57**

Figure 4-2: Estimating risk for the scenarios

For example, for scenario R (Figure 4-1), the severity of harm is considered to be injuries requiring more than first aid (medical assistance), with lost time, and so it was assigned a rank of 2 in the table. For the frequency of exposure to the hazard, scenario R is subject to exposure continuously, and so is assigned a rank of 5 in the table. Similarly, the duration of exposure to the hazard is considered to be continuous, and so is assigned a rank of 5. The probability of occurrence of a hazardous event is significant and is also assigned a rank of 5; and the possibility of avoidance appears to be unlikely, and so is assigned a rank of 4.

Consequently, the risk value is calculated as follows: $R_{\text{Scenario R}} = 2*(5+5+(2*5)+4) = 48$.

4.6.2 Evaluation of the Proposed Tool

In order to evaluate the proposed tool, the sequence of scenarios is assessed based on the risk values of the individual scenarios, which are shown in Figure 4-3. The risk values are rounded to their upper bounds, while their equivalent percentage values are used for comparing the sequences. These values are as follows:

- Ranks between 1 and 25 ~ 20%.
- Ranks between 26 and 50 ~ 40%.
- Ranks between 51 and 75 ~ 60%.
- Ranks between 76 and 100 ~ 80%.
- Ranks between 101 and 125 ~ 100%.

For example, for scenario R, the calculated risk value is 48. This value is in the 26 to 50 range, which corresponds to 40%.

20	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	60	60	60	100
A	B	C	D	E	F	H	G	I	J	K	M	N	O	P	R	L	Q	S	T
0	0	0	0	0	0	1*	1	0	0	0	1*	1*	1*	1*	2*	5	1	0	0

Figure 4-3: Sequence of scenarios to which the proposed tool is applied

The risk values for the scenarios should follow the order A to T, or be close to it. The sequence of scenarios is compared by counting the number of intervals (i.e. the distance) between their current position and where their actual letter (A to T) must be situated. If a scenario is considered to have a lower risk, the number is coloured in red, the number is shown with an asterisk.

With our proposed tool, scenarios H, M, N, O, P, and R are considered to have lower than expected risk levels. As a result, the tool is a low-estimating tool. Based on the report by Chinniah, Gauthier et al. (2011), a low-estimating tool gives a lower average risk than the overall average for the scenarios (48.8%). With an overall average of 38.9%, the tool proposed in this paper is, in fact, a low-estimating tool.

Figure 4-3 also shows that scenarios G, L, and Q are considered more risky than they actually are. However, this would not be an issue when assessing risk in real life situations.

4.6.3 Comparing Scenario Sequences

The sequence of scenarios for the proposed tool was compared with that used for each of the five selected tools. This comparison is shown in Figure 4-4. Chinniah et al. (2011) categorized scenarios in terms of their risk values: low risk (A to C), medium-low risk (D to J), medium-high risk (K to P), and high risk (Q to T). Their categorization was based on the number of times a scenario was evaluated as having the lowest or highest risk values. A similar categorization scheme was applied in this research.

Each of the five tools, as well as the proposed tool were used to generate a sequence of the scenarios based on an increasing risk value. Then, the sequence of scenarios for each tool was compared to the original order of A to T. The number of intervals between their current and original positions was counted, and the Sum of Differences was calculated, whether the scenario was considered a lower risk or a higher risk.

The colour codes in Figure 4-4 show the scenarios in their original four categories of low to high risk. In evaluating the performance of the tool in this research, it is not critical if a scenario is not in its original location, as long as it is still in its original risk category.

The comparison demonstrates that the sequence of scenarios obtained using the proposed tool is very similar to the original A to T sequence. Disregarding the fact that some of the scenarios have been placed in their risk categories incorrectly, the only scenarios that do not follow the sequence are R and L. Scenario R, with a 2-interval difference, is considered a medium-high risk scenario, instead of a high risk scenario. In fact, we observe that the risk associated with this scenario according to the assessment tool results is lower than it actually is, which could make the evaluation incorrect. However, the extent of this misplacement is only marginal and can be overlooked.

Scenario L is considered more risky than it actually is, as it had been assigned to the high-risk category instead of the medium-high risk category. Although this can divert attention away from more risky scenarios, the interval difference is low, and only marginally affects the performance of our proposed tool.

TOOLS	LOW			MID-LOW							MID-HIGH						HIGH				SUM of DIFFERENCES	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Lower	Higher
Proposed	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	60	60	60	100		
	A	B	C	D	E	F	H	G	I	J	K	M	N	O	P	R	L	Q	S	T		
	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	2	5	1	0	0	7	7
BT	16.7	33.3	50	50	50	50	50	50	50	50	50	50	50	50	83.3	83.3	83.3	83.3	83.3	100		
	B	F	A	C	D	E	G	H	I	J	K	L	O	R	M	N	P	Q	S	T		
	1	4	2	1	1	1	0	0	0	0	0	0	2	4	2	2	1	1	0	0	11	11
Company A	26.7	73.3	73.3	73.3	80.0	80.0	80.0	80.0	80.0	80.0	86.7	86.7	86.7	86.7	86.7	93.3	93.3	93.3	93.3	100.0		
	A	D	E	K	H	L	M	N	O	S	C	F	I	J	P	B	G	Q	T	R		
	0	2	2	7	3	6	6	6	6	9	8	6	4	4	1	14	10	1	1	2	49	49
SUVA	33.3	33.3	33.3	33.3	33.3	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	100.0	100.0	100.0		
	A	D	F	G	H	B	C	E	I	J	K	L	M	N	P	R	S	O	Q	T		
	0	2	3	3	3	4	4	3	0	0	0	0	0	0	1	2	2	3	2	0	16	16
NORDIC	33.3	66.7	66.7	66.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
	D	A	G	H	B	C	E	F	I	J	K	L	M	N	O	P	Q	R	S	T		
	3	1	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	11	11
Gondar	33.3	33.3	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3	100.0		
	B	M	C	E	F	I	J	K	L	O	A	D	G	H	N	P	Q	R	S	T		
	1	11	0	1	1	3	3	3	3	5	10	8	6	6	1	0	0	0	0	0	31	31

Figure 4-4: Comparison of the scenario sequences

When the Sum of Differences is calculated, the value obtained for the proposed tool is lower than the value obtained for the other five tools. This value gives the difference between the current scenario order and the original scenario order of A to T.

The Sum of Differences for each of the scenarios considered less risky is compared with that of the proposed tool and the other 31 tools. This comparison is illustrated in Figure 4-5. The first row in Figure 4-5 demonstrates the tool presented in this paper as well as the 31 tools which are referred to with a number and can be found in Gauthier et al. (2012).

TOOL #	44	35	48	46	41	66	7	89	Proposed RA	3	17	33	57	BT	NORDIC	94	85	19	6	58	45	SUVA	55	24	34	114	10	Gondar	69	49	91	Com A
LOW (DIFFERENCE)	0	1	1	1	2	4	5	6	7	7	10	10	10	11	11	12	13	13	14	15	16	16	19	21	22	30	30	31	32	42	46	49

Figure 4-5: Positioning of tools

All the eight tools that are positioned ahead of the proposed tool are of the risk matrix structure type, although this does not necessarily mean that the risk matrix tools are more precise than the proposed risk estimation tool, because tools such as BT, SUVA, and Gondar, which are positioned later in the sequence, are also risk matrix tools. Moreover, risk graph tools (e.g. tools 19 and 91) and numerical scoring tools (e.g. SUVA and tool 53) appear later in the sequence than the proposed tool.

4.6.4 Correlation Analysis

A correlation analysis was performed to determine the degree of the relationship between the proposed risk estimation tool and the five selected tools. This analysis would specify the extent to which changes considered in the structure of the proposed tool is associated with other risk estimation tools.

The average risk values of the 20 scenarios assessed for the 31 tools, as well as for the proposed tool, were calculated. The analysis was performed on the 32 tools with a confidence level of α=0.05 and 30 degrees of freedom. The null hypothesis is as follows:

H0: There is a correlation between the structures of the proposed tool and those of the other risk estimation tools.

Even though all 31 tools were considered in the correlation analysis, the behaviours of the five selected tools and that of the tool proposed in this paper will be discussed. Figure 4-6 summarizes the results of this correlation analysis.

To determine the likelihood that the correlation coefficient values occurred by chance, the Critical Value Table for Pearson's Correlation Coefficient from Siegle (2009) was used. Correlation coefficient values above 0.349 would indicate a statistically significant relationship between the respective risk estimation tools.

	Proposed RA	*BT*	*SUVA*	*Gondar*	*Company A*	*NORDIC*
Improved RA	1.000	0.704*	0.650*	0.382	0.334	0.359

Figure 4-6: Correlation analysis

Results show that all the correlation coefficient values are above 0.349 for every tool, which means that there is a significant relationship between the proposed tool and the five selected ones, and H0 is accepted.

In this analysis, values higher than 0.6 are assumed to indicate a high correlation (shown with an asterisk in Figure 4-6), and those below 0.6 indicate a moderate correlation. Correlations between the proposed tool and the BT tool and the SUVA tool are high (0.704 and 0.65 respectively). In support of these results, the risk estimation in the case of the BT tool was performed by multiplying the severity of the harm and the likelihood of harm, which is the same methodology as we use in our proposed tool. In the SUVA tool, the probability of harm is calculated by adding the following parameters: frequency and duration, probability of a hazardous event, and avoidance of a hazardous event. These parameters are similar to those applied in the proposed tool. Moreover, the SUVA tool assigns a weight of 2 to the parameter: probability of occurrence of a hazardous event, which is similar to the approach taken for our proposed tool.

None of the selected tools uses all five parameters that were included in the proposed tool. The NORDIC tool is the most similar to the new tool, in terms of the risk parameters used. With regard to the risk levels assigned to each parameter, the NORDIC and SUVA tools use the same number of levels (5) for the parameters: probability of occurrence of a hazardous event, and frequency of exposure to a hazard, as in the proposed tool. Also, the number of risk levels (5) in the SUVA tool is the same as in the proposed tool for the parameter: severity of harm.

These similarities justify the high degree of correlation between the proposed tool and the five selected tools. Therefore, it can be concluded that the proposed tool not only has similar functions to those in other risk estimation tools, but also is an improvement on those tools. The benefits and limitations of this tool are explored in the following section.

4.7 Benefits and Limitations of the Proposed Tool

To highlight the contributions of this research, the main benefits and limitations of the proposed tool are explored in this section.

The benefits of the proposed tool, include the following:

1. **It is functionally similar to other risk estimation tools.**

The functions of the proposed tool have a similar theoretical foundation to that of most of the other tools currently in use, the risk matrix tools, for example. One of the tool's main benefits is that the analysts working with it do not need to understand the underlying theory.

2. **It is applicable to any sector.**

The proposed tool can be used for estimating risk in general, and is not specifically designed for a particular situation, that is, it is not industry-specific. Consequently, it can be widely applied in the manufacturing sector.

3. **It covers different areas of OHS.**

This tool can be used for an initial risk for the purpose of prioritizing interventions. If required, more specialized tools can be used for specific hazards or particular OHS issues, like ergonomics, and environmental issues, like fatigue (physical or mental), incorrect posture, and chemical hazards.

4. **It defines detailed risk parameters.**

Five risk parameters have been defined for assessing hazardous scenarios in this tool: severity of harm, frequency of exposure to a hazard, duration of exposure to a hazard, probability of occurrence of a hazardous event, and the technical and human possibility of avoiding or limiting the harm. These risk parameters are carefully differentiated; for example, the frequency and duration of exposure are considered as two separate parameters in the risk estimation approach, as it is believed that doing so better captures the nature of the exposure to the hazard. Often, these two parameters, although different, are lumped together in one parameter in risk estimation tools, or, worse still, only one of them is considered. The use of detailed risk estimation parameters makes it possible to consider, and document, all the factors at play in estimating risk, as well as identify potential risk reduction measures which could act on those different factors.

5. **It defines detailed levels of risk estimation parameters.**

The levels for each parameter are precisely defined, in such a way that subjectivity is minimized. This helps to prevent disagreements among analysts, while at the same time producing more consistent results. Five levels for each parameter are used, with no gap or discontinuity between them.

6. **It includes sufficient levels of risk.**

The proposed tool has 4 or 5 levels of risk, ranging from very low to very high. This is consistent with the majority of risk estimation tools, but the number is small enough that risk does not tend to be overestimated.

7. **Its risk estimation formula has been configured to include weighting.**

The risk estimation equation takes into account differences in the degree of importance of the parameters by assigning weights to them. This helps to prevent one parameter overly influencing the risk level. For example, the parameter: likelihood of occurrence of a hazardous event, which can be technical in nature or based on human element has a higher rank than the other parameters. In the proposed tool, its weighting is double that of the other parameters. It is believed that estimating residual risk after the implementation of safety measures will be more realistic.

8. **It takes a pseudo-quantitative risk estimation approach.**

The proposed risk estimation tool is pseudo-quantitative, which makes it simple to incorporate into quantitative analyses. Because models for solving facility layout problems do not directly address safety issues, OHS features are rarely investigated in facility planning, in terms of exposure to risk for work-related injuries. This tool can be used to integrate OHS into the next generation of facility planning models.

The 20 hazardous scenarios in this paper refer to both real and potential applications of risk estimation tools to manufacturing and production systems. The ability to represent the risk posed by every hazardous scenario with a quantitative risk value will enable facility planners to design the most appropriate layout based not only on cost, flow, etc., but on safety factors as well. The contributions of the new risk estimation tool are its ability to deliver improved safety by using more precise risk parameters and levels, its comprehensiveness in terms of applicable situations and OHS features, and its pseudo-quantitative and balanced risk estimation formula. It is believed that the proposed risk estimation tool will provide more accurate results than the risk tools currently in use.

4.7.1 Limitations

One limitation of the study is that the proposed tool needs to be tested by different practitioners. So far, it is confirmed that the tool has all the theoretical characteristics of a well-balanced tool; its parameters are well defined; and it contains all the parameters required for risk estimation. The equation it uses appears to yield good results, in terms of discriminating among the scenarios and in identifying the scenario sequence from low risk to high risk.

While the scenarios for this paper were mostly taken from the manufacturing sector, hazardous scenarios from the services sector can be developed and the applicability of the model in this context tested.

The proposed tool can require more time than some of the simpler existing techniques since one has to consider more parameters, more levels for each parameter as well as to calculate risk using an equation. Besides, it could require more than one analyst to evaluate the risk scenarios; therefore fair assignments of ranks to the risk parameters are assured.

4.8 Conclusion

There are a number of methods for estimating risk, and choosing the tool that best suits a company's needs can be a challenge. This paper has presented a proposed tool for risk estimation, which will be able to enjoy general use in a wide range of industrial contexts. The proposed tool is intended to facilitate the integration of OHS into the design of a plant layout.

Twenty risk scenarios have been assessed based on five risk parameters, and the results used to calculate a risk value based on the risk estimation model considered. The risk values were evaluated based on the degree of risk, from low to high, assigned to each scenario. Furthermore, the performance of the proposed tool was compared with that of the other risk estimation tools considered. The sequence of scenarios for the proposed tool turns out to be very close to their original order of A to T. Also, the Sum of Differences in considering a scenario shows it to be less risky than it actually is, and this risk is much lower with the proposed tool than with most of the other tools evaluated.

Future research will be aimed at proposing a methodology by which facility planning models and risk estimation tools can be integrated, in order to better meet the safety requirements of companies. This means that it will be possible to design a facility layout in the form of a mathematical model while considering OHS issues as constraints of the model. Therefore, the output from the proposed tool in this paper can be used as an input to a facility planning model in which OHS is considered as important a factor as other factors in facility layout problems, such as cost, proximity, material flow, flexibility, and material handling system concerns.

Combining the risk estimation concept with the literature on organizational knowledge can be another interesting line of future research. For instance, Bohn (1994, 2005) provides a framework of the stages of technological knowledge. In the initial stages, there is an organizational unawareness of the risks inherent in manufacturing processes. Therefore, protective action should be taken at the initial stages (e.g. using robots), in cases where risk has not been identified, assessed, and quantified. In the final stages, preventive actions will be more important.

The research can also be enriched by evaluating the proposed tool in real case studies. This could support validation of the practicality of the tool, with regard to its generalizability to many situations and its independence of the nature of those situations.

Acknowledgments

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CHAPTER 5 ARTICLE 2: INTEGRATING OCCUPATIONAL HEALTH AND SAFETY IN FACILITY LAYOUT PLANNING, PART I: METHODOLOGY

Abstract[3]

An influential factor affecting the efficiency of a manufacturing facility is its layout. In a production facility, measure for efficiency can be based on the total cost of transporting the items between different departments and throughout the facility. However, other factors may influence efficiency of the manufacturing facility too. As such are: supporting the organisation's vision through improved material handling, material flow and control; effectively assigning people, equipment, space and energy; minimising capital investment; adaptability and ease of maintenance; as well as providing for employee safety and job satisfaction. By incorporating health and safety measures in the initial design of a facility layout, the organisation may avoid money and manpower loss resulting from industrial accidents. This paper proposes a facility layout planning methodology which integrates the occupational health and safety (OHS) features in the early design of a facility layout. The model considers transportation cost in the facility as well as safety concerns. By this means, the OHS issues are reflected prior to the construction of a facility.

Keywords: facility planning model, layout design, occupational health and safety (OHS), risk estimation

5.1 Introduction

Efficient design of a facility layout is recognized as one of the most important issues in manufacturing companies. Lower unit cost and higher quality are among the main objectives, and

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flow time and lateness are among the most commonly used performance measures of efficiency in manufacturing systems (Zolfaghari and Roa, 2006). Consequently, facilities layout design is an important industrial issue as it directly and indirectly results in higher efficiency of the system (Rawabdeh and Tahboub, 2006).

Facility layout has been formally studied as an academic area of research since the early 1950s (Benjaafar et al., 2002). Facility layout design is regarded as the key to the performance improvement of manufacturing system (Tarkesh et al., 2009). The layout problems appear in many fields of applications. It aims to obtain the most effective facility arrangement and minimize the material handling costs (De Alvarenga and Negreiros-Gomes, 2000). Facility layout design considers the design of layout, the accommodation of people, the machines and activities of a system within a physical spatial environment. Research results indicate that 20-50% of the total costs in manufacturing has direct or indirect relationships with material handling (Lin et al., 2013).

Traditionally, planning a layout starts by creating a layout diagram for the departments. The design then proceeds in iterations until a compromise is reached, which more or less satisfies all the known factors and restrictions (Whitehead and Eldars, 1965). Therefore, a layout is developed using relationships among various departments, based on the judgement of experts who decide the importance of relationships between each pair of departments. However, the decision of experts can be vague and usually based on many quantitative and qualitative considerations; e.g. flow of materials between departments or the ease of supervision of employees (Karray et al., 2000).

One of the difficulties in developing and using facility layout models is the natural vagueness associated with the inputs to these models (Deb and Bhattacharyya, 2003). The facility layout models consider assignment of departments to locations so that the quantitative or qualitative objectives of the model are minimized or maximized (Shouman et al., 2001). The most common objective used in quantitative methods is to minimize the materials handling cost. Qualitative methods, on the other hand, consider a subjective numerical proximity weight to express the desirability of having any two departments close to each other on the layout (Karray et al., 2000).

The majority of previous research on facility planning focused upon optimizing costs and closeness relations. However, qualitative factors such as the plant safety, flexibility of layout for future design changes, noise and aesthetics must be considered as well; e.g., a proper machine tool selection has been very important issue for companies for years (Ayag and Ozdemir, 2006). Above all, the association between facility layout and occupational health and safety (OHS) is not extensively reflected in developing models. OHS ensures the safety and health of workers by setting and enforcing standards and encouraging continual improvement in the workplace safety (OSHA, 2007). It is estimated that at least 250 million occupational accidents occur every year worldwide, where 335 000 of those are fatal (ILO, 2012). Indeed, proper OHS considerations confirm regulatory compliance, improves productivity and wellbeing of personnel, keeps the cost down by avoiding stoppage time following accidents and investigation; thus OHS contributes positively to the overall performance of the company (Jallon et al., 2011a, b). In order to ensure sustainability of OHS, risk estimation methods are used.

Risk estimation is a series of steps used to examine hazardous situations. Methods of identifying hazard and estimating risks take many forms, while offering different perspectives with different strengths and weaknesses. Each method begins with potential hazards or failures, whereas each uses a system to evaluate risks and to identify necessary protective measures. In general, any improvement to safety of a situation or machine begins with risk estimation (Giraud, 2009).

OHS regulations are vast; yet, do not cover all the rules and regulations that apply to facility planning and layout design. When developing a facility layout, designers should note these constraints such as the fact that some department pairs need to be in adjacent sites for safety reasons (Tompkins, 2010) regardless of the volume of material flow between them. As a result, practical facility layout should meet multiple objectives rather than a single objective (e.g. material handling cost). Multiple objectives models for layout design, especially qualitative objectives such as safety, need further research. In an effort to improve the facility layout planning models, this paper investigates how facility planning models and risk estimation tools can be integrated to provide a robust model to better meet productivity and safety requirements.

In this regards, models of facilities planning along with their objective, constraints and methodologies are studied. A similar approach was used for the risk estimation tools by comparing their characteristics and parameters. The outcome of this paper proposes a model which integrates OHS in the facility layout planning models. As a result, safety would be considered as important as other factors such as cost or space constraints. The proposed model is applied to a case study which is presented in the Part II of the paper.

5.2 State of the Art

Facility layout problems as well as the influence of including aspects of OHS in layout models are the two main features of this research. They are elaborated in following paragraphs.

5.2.1 Facility Layout models

Typical plant layout procedures determine how to arrange various machines and departments to achieve minimization of overall production time, maximization of turnover of work-in-process, and maximization of factory output (Djassemi, 2007). Characteristics of the facility that influence design of the layout could clearly differentiate the nature of facility planning models. Several factors and design issues are addressed in the literature, in particular: the production variety and volume, the material handling system chosen, the different possible flows allowed for parts, the number of floors on which the machines can be assigned, the department shapes, and the pickup and drop-off locations (Drira et al., 2007). These factors are detailed below.

- **Specification of the manufacturing system**

The layout design generally depends on the products variety and the production volumes, from which, four types of organization are referred to:

  - Fixed product layout
  - Product layout
  - Process layout
  - Cellular layout

- **Department shapes**

Two department shapes are often distinguished:

  - Regular: rectangular
  - Irregular: polygons with 270^{o} angle

- **Department dimensions**

A department can be defined by its:

- Area, aspect ratio, upper and lower bound
- Fixed or rigid blocks: with fix length and width

- **Layout configuration**

The limitation of available horizontal space creates a need to use a vertical dimension of the department. Hence, it can be relevant to locate the departments on several floors instead of a single one.

- Multi-floor layout
- Single floor layout

- **Flow of material**

Backtracking and bypassing are two particular movements that can occur in flow-line layouts, which impact flow of the products.

- With bypassing
- With backtracking

- **Layout evolution**

Nowadays, manufacturing plants must be able to respond quickly to changes in demand, production volume and product mix. Therefore, the idea of dynamic layout is considered in addition to the static layouts.

- Static layout
- Dynamic layout

The main objective of the facility layout model is to minimize a function related to the travel of parts; e.g. the total material handling cost, the travel time, and the travel distance. Other minimization models can be associated with space cost, rearrangement cost, equipment flow, information flow, backtracking and bypassing, traffic congestion, and shape irregularities. A facility layout model can also aim to maximize the adjacency function which is the assessment of the proximity between two departments. Some researchers considered more than a single objective. A multi-objective model was introduced by Dweiri and Meier (1996) aiming at simultaneously minimizing the material handling flow and the equipment flow and the information flow. Chen and Sha (2005) combined objectives into a single one by using a linear combination of the different objectives.

5.2.2 Facility Planning Approaches

Since the late 1950s a number of algorithms have been developed to solve the facility layout model, classified as:

1. **Optimal algorithms:** these algorithms, which were developed to solve quadratic assignment problems (QAP), fall into two classes:

a) Branch and bound algorithms; e.g. Ahmed (2013); Burkard and Rendl (1984); Gendron et al. (2013); Ghaderi and Jabalameli (2012); Gortz and Klose (2012); Kim and Kim (2010); Roucairol (1987).

b) Cutting plane algorithms; e.g. Brandenberg and Roth (2011); Burkard (1984); Chouman et al. (2009); Gollowitzer et al. (2013); Vasilyev and Klimentova (2010).

Common disadvantages of optimal algorithms are the high memory and computer time requirements, while the largest problem solved optimally is a problem with 15 departments. This has encouraged researchers to use sub-optimal algorithms.

2. **Sub-optimal algorithms:** many researchers developed sub-optimal algorithms to also deal with QAP. These algorithms are classified as: (i) construction algorithms in which a solution is constructed from scratch, (ii) improvement algorithms in which an initial solution is improved, (iii) hybrid algorithms which are combinations of two optimal or sub-optimal algorithms, and (iv) graph theoretic algorithms.

Based on these approaches, computerized techniques for the design or the improvement of a layout are proposed. Some of them are CRAFT, COFAD, CORELAP, ALDEP, PLANET, SHAPE, MULTIPLE (Bozer et al., 1994), and BLOCPLAN (Katzel, 1987). The Systematic Layout Planning (SLP) method of Muther (1973) is not only a proven tool in providing layout design guidelines but is still widely used among enterprises and the academic world (Chien, 2004).

Major drawbacks of the aforementioned approaches lie in the fact that the search for the best layout is not very efficient and the multi-objective nature of the facilities layout models is not considered (Hillier and Connors, 1966). Many studies focussed on new and recent developments rather than conventional approaches to overcome these drawbacks. Intelligent techniques are presented as new advancements to tackle the problem.

3. **Meta-heuristics algorithms:** different meta-heuristics algorithms and techniques are presented to solve facility planning models; the most well-known of these systems are: neural networks (e.g. Zhang and Huang (1995); Tsuchiya et al. (1996); Cook et al. (2000)), genetic algorithm (e.g. HOPE by Kochhar et al. (1998); MULTI-HOPE by Kochhar (1998); Hamamoto (1999); and Cheng et al. (1995)), simulated annealing (e.g. Heragu and Alfa (1992); Meller and Bozer (1996); and Misevicius (2003)), tabu-search (e.g. Chiang and Kouvelis (1996); Abdinnour-Helm and Hadley (2000)), and ant colony optimization (e.g. Solimanpur et al. (2004); Pour and Nosraty (2006); and Hani et al. (2007)).

4. **Expert systems:** an expert system is defined as a special purpose computer program used to imitate the decision making process of a human expert in a specific knowledge domain of limited scope (Shouman et al., 2001). Several expert systems have been proposed for the facility layout models; as such are KBML (Sunderesh and Kusiak, 1990), IFLAPS (KumaraKashyap et al., 1988), FADES (Fisher and Nof, 1984), as well as the models presented in Harraz (1997) and Sirinaovakul and Thajchayapong (1994).

5. **Fuzzy systems:** they provide a formal system for representing and reasoning with uncertain information. Several implementations of the fuzzy system are proposed, including the research by Dweiri and Meier (1996), Raoot and Rakshit (1993), Evans et al. (1987), and Whyte and Wilhelm (1999).

6. **Intelligent hybrid systems:** hybrid approaches aim to integrate more than one technique when solving a specific problem. Some of the proposed models are presented by Chung (1999), Cheng et al. (1995), Pham and Onder (1992), and FLEXEPRET by Adedeji and Arif (1996).

There are plenty of tools and approaches which allow taking into account different aspects of a facility layout model and which provide solutions for a relatively large number of problems.

From the numerous models and methods proposed for the abovementioned approaches, OHS in Facility Layout Planning

The implementation and certification of quality, environmental and OHS systems has been a major activity for many organisations in light of increasing pressure from their internal and external stakeholders including the regulatory bodies, community, customers, employees, suppliers and the government (Zutshi and Sohal, 2005). However, providing safe and pleasant environment for personnel should be considered as early as when designing the layout of a facility.

The relationship between facilities layout and OHS has not been researched extensively. Chang and Liang (2009) developed a model, based on a three level multi-attribute value model approach, in order to evaluate the performance of process safety management systems of paint manufacturing facilities.

Fernandez-Muniz et al. (2007) developed a Safety Measurement System Scale, from the results of a questionnaire survey of 455 Spanish companies, in order to guide the safety activities of organizations. Following dimensions are considered: (i) a safety policy reflecting the organisation's principles and values; (ii) promotion of workers' involvement in safety activities; (iii) employee training; (iv) communication and transference of information about the risks; (v) action planning to avoid accidents; and (vi) control or feedback on actions taken in the organisation.

Terrier (2003) presented a guideline to take into account the risk of accidents and occupational diseases in the design phase of workplace implementation. This would enable avoiding unsatisfactory and technical difficulties in future workplace improvements. Tompkins (2010) presented the human factor risks as one of the criteria to be considered in the prioritization matrix for facilities design. In developing facilities design alternatives, designers need to consider the human factor risks. In that matrix, this criterion is compared using weights with other criteria such as the total distance travelled, manufacturing floor visibility, overall aesthetics, space requirements, people requirements etc.

Table 5.1 elaborates on some of them.

5.2.3 OHS in Facility Layout Planning

The implementation and certification of quality, environmental and OHS systems has been a major activity for many organisations in light of increasing pressure from their internal and external stakeholders including the regulatory bodies, community, customers, employees, suppliers and the government (Zutshi and Sohal, 2005). However, providing safe and pleasant environment for personnel should be considered as early as when designing the layout of a facility.

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Table 5.1: Survey of analytical solution methods for facilities layout models

Model	Technique	Objective	Comments
PLANET (Apple and Deisenroth, 1972)	Construction	Flow cost	Starts at centre, 2 facilities located at once
MAT (Edwards et al., 1970)	Construction	Flow cost	Allows user to assign departments to any desired location
ALDEP (Hales, 1984)	Construction	Closeness	Randomly selects a department, starts at upper left corner
SHAPE (Hassan et al., 1986)	Construction	Flow cost	Based on generalized assignment problem
FLAT (Heragu and Kusiak, 1986)	Construction	Flow cost	Departments of unequal areas, low compute time, good quality results
CORELAP (Lee and Moore, 1967)	Construction	Closeness	Selects first facility depending on total closeness value
HC66 (Nugent et al., 1968)	Construction	Flow cost	Uses criteria of Vogels' approximation in TP
LSP (Zoller and Adendorff, 1972)	Construction	Closeness	High computational efforts, similar to ALDEP, flexibility
CRAFT (Buffa et al., 1964)	Improvement	Flow cost	Up to 40 departments, does not perform well for departments of unequal areas, uses 2- and 3-way exchanges for smoothing irregular shapes
H63 (Nugent et al., 1968)	Improvement	Flow cost	Only pairwise exchanges between adjacent departments, only for departments of equal areas, based on a move desirability table
HC 63-66 (Nugent et al., 1968)	Improvement	Flow cost	Limits the exchanges only to departments which lie on a horizontal, vertical or diagonal line, only for departments of equal areas, a modification of H63, allows exchange of non-adjacent departments.
Revised Hillier (Picone and Wilhelm, 1984)	Improvement	Flow cost	Uses H63, considering 4-way perturbations, produces solutions at least as good as H63, more computation time than H63

Table 5.1: Survey of analytical solution methods for facilities layout models (continued)

Model	**Technique**	**Objective**	**Comments**
COFAD (James and Ruddell Jr, 1976; Tompkins and Reed Jr, 1973)	Improvement	Flow cost	MHS selection, uses CRAFT, jointly considers layout and material handling system, more realistic layouts
DISCON (Drezner, 1980)	Hybrid	Closeness	Dispersion phase provides good starting points, difficult to justify the outcome, uses a two-phase algorithm of dispersion-concentration
KTM (Kaku et al., 1991)	Hybrid	Flow cost	Uses 2- and 3-way exchanges, a combination of construction and improvement, very good results within very little computer time
FLAC (Scriabin and Vergin, 1985)	Hybrid	Flow cost Closeness	Has three stages, a combination of construction and improvement
Wheel Expansion (Eades et al., 1982)	Graph Theoretic	Adjacency	Similar to Deltahedron
Branch and Bound (Foulds and Robinson, 1978)	Graph Theoretic	Adjacency	Obtain optimal solution, a require maximal planar graph
Deltahedron (Foulds and Robinson, 1978)	Graph Theoretic	Adjacency	Avoid the testing of planarity
FADES (Fisher and Nof, 1984)	Expert System	Flow cost Closeness, Materials handling cost	Knowledge-based approach, for solving general facility design problems, selecting equipment that meets the required technology level and performing economic analysis, written in PROLOG
IFLAPS (Kumara et al., 1988)	Expert System	Adjacency	In FORTRAN, does not involve paired comparisons between departments or the overall, relationship between various departments
KBML (Sunderesh and Kusiak, 1990)	Expert System		For machine layout in automated manufacturing systems, a forward-chaining inference strategy is utilized

Table 5.1: Survey of analytical solution methods for facilities layout models (continued)

Model	**Technique**	**Objective**	**Comments**
(Tsuchiya et al., 1996)	Neural Network		Near-optimum parallel algorithm, for an N-facility layout problem, BEING capable of generating better solutions over the existing algorithms for some of the most widely used benchmark problems
HOPE (Kochhar et al., 1998)	Genetic Algorithm		For solving single-floor facility layout problem, considered departments of both equal and unequal sizes, results indicated that GA might provide a better alternative in a realistic environment where the objective is to find a number of reasonably good layouts
MULTI-HOPE (Kochhar, 1998)	Genetic Algorithm		Multiple-floor layout problems, extends HOPE algorithm, averagely gives a better solution than existing multi-floor layout algorithm
(Dweiri and Meier, 1996)	Fuzzy System	Flow cost Closeness	AHP is used to find the weights of qualitative and quantitative factors affecting the closeness rating between departments, a modified version of CORELAP (FZYCRLP) is used
(Raoot and Rakshit, 1993)	Fuzzy System	Flow cost Closeness	Considers organizational links optimisation. A linguistic pattern approach for multiple criteria facility layout problems.
FLEXEPRET (Adedeji and Arif, 1996)	Intelligent Hybrid System		A fuzzy-integrated expert system, generates the best layout that satisfies the qualitative as well as the quantitative constraints on the layout problem, VP-Expert is used
(Chung, 1999)	Intelligent Hybrid System		A neural expert system, creates effective multi-bi-directional generalization behaviour, goal-driven layout design experience

The use of risk analysis when designing a facility is mentioned by Brauer (2006). The author argues that the best time to incorporate safety into a facility is during the planning and design of a new facility or the modernization of an existing facility. A tool consisting of a list of safety considerations in facility planning is also presented, in which, a facility design is broken into several components, namely: (i) site and siting; (ii) building or facility; (iii) interior and occupancy; (iv) workstations; (v) equipment; and (vi) operations, processes or activities.

Moatari-Kazerouni et al. (2012) developed a comprehensive list of safety criteria or facility managers to consider in the early stages of the plant design to improve OHS. These criteria reflects on: (i) safety policies reflecting the hazards caused by machinery; (ii) safety in designing material handling system and machinery movement; (iii) employees training, experience and flexibility of jobs; (iv) safety in maintenance and services; (v) characteristics of material used in the manufacturing process; and (vi) environmental aspects of safety.

Furthermore, the models for solving layout problems do not directly include OHS aspects. A new trend in designing plant layouts consists of extending the layout formulations with safety issues. Various mixed integer linear programming models were proposed to reduce financial costs, in which certain aspects of safety were also considered (Papageorgiou and Rotstein, 1998; D. Patsiatzis et al., 2004; D. I. Patsiatzis and Papageorgiou, 2002; Penteado and Ciric, 1996). Some artificial intelligent techniques were proposed which consider both quantitative and qualitative factors, including safety and ergonomics. As such, Pham and Onder (1992) developed a knowledge-based system for optimum workplace design. The combination of knowledge-based technology, genetic optimization methods, and database technology is proved to be an effective way to build powerful knowledge-based systems for solving complex ergonomic design problems. In the research by Carnahan and Redfern (1998), a genetic algorithm is applied to the problem of designing safe lifting tasks within the constraints of the work place. Also, Pham and Onder (1991) proposed an expert system for ergonomic workplace design by using a genetic algorithm approach.

In order to evaluate OHS in a facility, potential hazards of the layout design should be identified and risk estimation be conducted. Risk estimation is the process during which managers should analyse the potential impacts of the identified risks to the organisation (Lee et al., 2013). It is traditionally based on collecting and evaluating data on severity of an injury and probability of occurrence of the event. In other words, risk is reduced when a protective action such as change of design, use of safeguard, or application of safe procedure is implemented, that meaningfully reduces severity of injury or probability of occurrence of harm (Etherton, 2007). The severity of harm can be estimated by taking into account:

- the severity of injuries or damage to health; e.g. slight, serious, or fatal
- the extent of harm; e.g. to one person or to several people

Probability of occurrence of harm can be estimated by taking into account:

a) Nature of the exposure of people to the hazard
    - reason to access the hazard zone, e.g. for normal operation, correction of a malfunction, maintenance, or repair
    - nature of access; e.g. manual feeding of materials
    - time spent in the hazard zone
    - number of people requiring access
    - frequency of access

b) Occurrence of a hazardous event
    - reliability of statistical data
    - accident history
    - history of harm to health
    - risk comparison

c) Technical and human possibility of avoiding or limiting the harm
    - the people involved i.e. who may have been exposed to the hazard (skilled or unskilled workers)
    - how quickly the hazardous situation could lead to harm, e.g. suddenly, quickly, or slowly
    - awareness of risk, e.g. generally available information, user manuals, direct observation, warning signs, and warning devices on the machinery

– the human capacity to avoid or limit harm, e.g. reflexes, agility, possibility of escape

– practical experience and knowledge, e.g. knowledge of the machinery or of similar machinery, or the absence of experience or knowledge.

5.3 Research Objectives and Methodology

Minimizing material handling and transportation cost is one of the most researched objectives in facility layout models, but it is not the only factor that must be taken into account when designing a layout. Other factors such as travel time and distance between departments, equipment and information flow, space and rearrangements costs, backtracking and bypassing, or traffic congestion are also significant. So is the occupational health and safety in regards to the facility arrangements and equipment, building, and the personnel.

The objective of this paper is to propose a facility planning model which integrates the OHS aspects in layout design of a facility. The model is based on the cost reduction objective while it does not disregard safety of locating departments close to each other. In other words, the model would value OHS as an important factor as cost in locating departments in the layout.

Pursuing this objective, the overall research methodology consists of the following stages:

1. Facility layout planning models as well as risk estimation tools were reviewed.
2. A risk estimation tool is proposed for being included in the facility planning model.
3. A facility planning model is developed which embraces the concept of integrated OHS in layout design.
4. Restrictive assumptions, for which the proposed facility planning model is valid, are presented.

5.4 A Model for Integrating OHS in Facility Planning

The model consists of four steps. The first step concentrates on traditional cost factors. The second step evaluates the layout by considering the OHS aspects. The third step proposes designing a first layout based on the cost factors (if an existing layout does not already exist). Finally, the fourth step explains how the former layout can be adjusted based on the safety aspects, and how the layout is improved by exchanging the positions of departments. As a result, the layout design is improved by inclusion of OHS aspects.

Inputs to the model are: an initial/existing layout or a 'from-to' chart as input data for the flow cost, and any constraint for considering a facility having a fixed-position with all restrictions such as two departments must not be located close to each other at any cost. Following sections explains the steps of the model in details.

5.4.1 Step I: Material Handling and Transportation Cost Factor

The first step concentrates on the relative placement of departments as measured by total material handling and transportation cost for the layout. Material handling and transportation cost between departments is calculated by multiplying "number of loads" by "rectangular distance between departments centroids" by "cost per unit distance" (Tompkins, 2010). Therefore, the initial inputs are the load matrix ('from-to' chart), the distance matrix, as well as the cost of carrying any material per unit distance.

In this regards, the first step is to determine centroids of departments and calculate rectilinear distance between the centroids. Obtained values result in creating the distance matrix.

Next step is to develop the material handling and transportation cost matrix. Material handling and transportation costs between pairs of departments are calculated by using Eq. (1). These values configure the cost matrix.

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} d_{ij} c_{ij} \qquad (1)$$

Where, *i* and *j* are the departments, *m* is the total number of departments, f_{ij} is the flow of material from the 'from-to' chart, d_{ij} is the distance from the distance matrix, and c_{ij} is the cost of carrying any material.

Subsequently, one should look for the highest value in the material handling and transportation cost matrix. Five cost categories will be defined according to their relative cost portions, where category 5 contains the highest cost values and category 1 the lowest (*see*

Table 5.2).

Table 5.2: Material handling and transportation cost categories

Cost Categories	**Cost Ranks**	**% of Occurrence of Cost Ranks**
Category 1 (lowest)	U	More than 50% have U
Category 2	O	Less than 40% have A, E, I or O
Category 3	I	Less than 25% have A, E or I
Category 4	E	Less than 12% have A or E
Category 5 (highest)	A	Less than 5% have A

The ranks assigned to the cost categories indicate the relative importance in closeness of the departments based on the cost factor. Considering that a higher transportation cost value states being more economical to place the departments closer to each other, these ranks are defined as: A- absolutely necessary, E- especially important, I- important, O- ordinary closeness OK, and U- unimportant. From a practical perspective it is expected that more than half the pairwise combination of departments will have a relationship of U. It is reasonable to expect less than 5% of the pairwise combinations to have A relationships, less than 12% to have either A or E relationships, less than 25% to have either A, E, or I relationship, and less than 40% to have A, E, I, or O relationships. Even with a high degree of sparseness in the layout design, the number of pairwise combinations can become unmanageable. Hence, caution must be used when dealing with a large number of departments (Tompkins, 2010).

The relative importance in closeness of the departments based on the cost factor can be demonstrated as a cost relationship diagram (Figure 5-1).

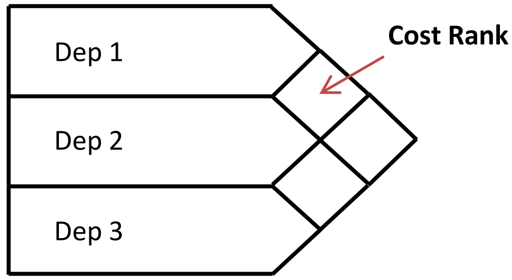

Figure 5-1: Material handling and transportation cost relationship diagram

5.4.2 Step II: OHS Evaluation

The second step concentrates on including OHS in the model. To begin with, the risk scenarios need to be developed. These scenarios are related to safety issues regarding the placement of departments versus each other in the initial layout.

For each risk scenario, qualitative levels of the five risk parameters have to be identified. These risk parameters are (1) severity of harm, (2) frequency of exposure to the hazard, (3) duration of exposure to the hazard, (4) probability of occurrence of a hazardous event, and (5) technical and human possibilities of avoiding or limiting the harm.

These parameters and their corresponding risk levels are presented in following paragraphs. The number of levels for each parameter has been determined from the equivalent scales as explained by Chinniah et al. (2011). Since these risk parameters are qualitatively scaled, they need to be transformed to quantitative measures in order to facilitate adopting them in the model. Therefore, a rating system is used in which quantitative values were assigned to levels of each risk parameter as their rates (see Table 5.3 - 5.7). These values are based on a 1 to 5 rating scales, where 1 indicates the lowest and 5 is the highest risk. The tool is developed and tested in Moatari-Kazerouni et al. (2014c) and the main points are summarized here.

- **Severity of harm (S)**

Severity of harm is defined as hazard in term of potential to cause harm. The likely effect of a hazard can be rated as in Table 5.3. The ranks are actual values which are used in calculating risk.

Table 5.3: Severity of harm

Severity of harm (S)	Rank
Slight injuries (bruises) requiring no first aid or injuries requiring first aid but without lost time	1
Injuries requiring more than first aid (assistance) and with lost time or when there is irreversible harm and slight disability, but the employee is able to return to the same job	2
Serious disability, the employee being able to return to work, but perhaps not to the same job	3
Permanent disability, and the employee can no longer work	4
One or more deaths	5

- **Probability of occurrence of harm (Ph)**

It is estimated by four parameters. These parameters and their risk levels are addressed in Table 5.4 - 5.7.

- **Frequency of exposure to the hazard (Exf)**

Table 5.4: Frequency of exposure to the hazard

Frequency of exposure to the hazard (Exf)	Rank
Less than once per year	1
Annually	2
Monthly	3
Weekly	4
Daily to continuously, i.e. several times per hour	5

- **Duration of exposure to the hazard (Exd)**

Table 5.5: Duration of exposure to the hazard

Duration of exposure to the hazard (Exd)	Rank
< 1/20 of work time	1
1/10 of work time (45 min per 8 hour shift)	2
1/5 of work time (90 min per 8 hour shift)	3
Half of work time (1/2) (4 hours per 8 hour shift)	4
Continuously during work time	5

- **Probability of occurrence of a hazardous event (Pe)**

Table 5.6: Probability of occurrence of a hazardous event

Probability of occurrence of a hazardous event(Pe)	Rank
Negligible	1
Unlikely	2
Possible	3
Likely	4
Significant	5

- **Technical and human possibilities to avoid or limit the harm (A)**

Table 5.7: Technical and human possibilities to avoiding or limiting the harm

Technical and human possibility of avoiding or limiting the harm (A)	Rank
Highly significant	1
Significant	2
Somewhat likely, with some conditions	3
Unlikely	4
Nil	5

To calculate the risk value for each of the risk scenarios, quantitative values assigned to the five parameters are used in the following equation.

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

The mathematical relations between the parameters, as well as the weight assigned to each of them, have been adjusted according to different risk estimation approaches introduced in literature. It includes all the risk parameters highlighted in ISO 12100, and is used to calculate the risk value for each scenario. Risk is calculated by multiplying the qualitative value of S by the qualitative value of Ph. This function is similar to the approach used in the BT (Worsell and Ioannides, 2000) and Gondar (GondarDesign, 2000) risk estimation tools.

To calculate a numerical value of the probability of occurrence of harm (Ph), an approach similar to that applied in SUVA (Bollier and Meyer, 2002) and NORDIC (Mortensen, 1998) risk estimation techniques was used. Four parameters are added: frequency of exposure to the hazard (Exf), duration of exposure to the hazard (Exd), probability of occurrence of a hazardous event (Pe), and possibility of avoidance (A). In this function, the weight for the Pe value is considered to be twice that of the other parameters. This is because the likelihood of occurrence of a hazardous event, which may be of a technical nature (e.g. system reliability) or caused by a person (e.g. error, fatigue), has a higher rank than the other parameters (Bollier and Meyer, 2002).

To explain thin risk estimation method, an example would be the noise hazard that occurs in operating large panel press. The ambient noise is above 85 dB which cause a hazardous situation and workers are in the vicinity.

Table 5.8 demonstrates assigning the numerical values of risk parameters and calculating the risk value for this hazardous situation.

Table 5.8: Risk value example

SCENARIO	**S**	**Ph**				**Risk Value R=S*(Exf+Exd+2*Pe+A)**
		Exf	**Exd**	**Pe**	**A**	
S	S5	Exf8	Exd5	Pe2	A1	
	3	5	5	2	1	**45**

In order to evaluate the risk values, five risk categories are defined. Since the maximum number obtained from the equation is 125 and the minimum is 1, the range of risk ranks were divided to 5 equal categories from 1 to 125. Risk categories are assigned to the corresponding range as demonstrated in Table 5.9. Moreover, these categories are ranked by scales of 1 to 5. A higher risk value indicates being less safe to place the departments closer to each other; therefore, 1 indicates the lowest and 5 is the highest closeness importance based on the safety factor.

Table 5.9: Risk value evaluation

Risk Value Ranges	**Risk Categories**	**Safety Ranks**
1-25	very low	5
26-50	low	4
51-75	medium	3
76-100	high	2
101-125	very high	1

The relative importance in closeness of the departments based on the safety factor can be demonstrated as a safety relationship diagram (Figure 5-2).

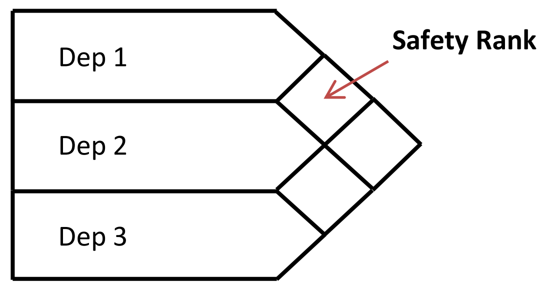

Figure 5-2: OHS relationship diagram

5.4.3 Step III: Layout Design Considering the Cost Factor

This step proposes how the departments should be located in the layout when considering the cost aspects.

For that, facility planners use the techniques explained in Section 5.2.2. The traditional approach can be used for locating the other departments in the layout; i.e. pair of departments with higher cost value should be placed close to each other (Tompkins, 2010).

The initial departments to be placed in the layout are the “fixed-positioned” departments which are considered as constraint inputs to the model. These departments have predefined positions in the layout and their locations cannot be swapped with other departments.

The procedure is repeated until all departments are positioned in the layout.

However, if an initial layout already exist and performs correctly considering the material handling and transportation cost, step IV may directly be applied. This is applicable when this proposed methodology is applied to an existing layout and for re-designing and improving the layout based on the OHS issues.

5.4.4 Step IV: Layout Improvements Considering OHS Aspects

In choosing which department pairs to enter the layout, this model suggests considering cost factor, followed by the safety aspect. However, the decision can be effected by different issues such as the priorities set by the company or the facility planner’s opinion. Therefore, it is recommended that, to the extent possible, to take into account both safety aspects and cost factors. In order to better guide facility planners in their decision making, a safety-cost relationship diagram can be designed as illustrated in Figure 5-3. The safety-cost relationship diagram is very similar to the Relationship Chart (Tompkins, 2010). In this diagram, the reason behind the importance of locating two departments close to each other is indicated, based on criteria of cost, safety as well as the opinion of the facility planner. This diagram would guide the facility planner in making decisions, when both safety and cost have significant influence. Thus, deciding the location of departments in the first layout design (step III) is influenced if safety issues recommend on the proximity of the departments.

Therefore, the new layout design process would start with facility planning group to prepare the safety-cost relationship diagram by comparing the “material handling and transportation cost relationship diagram (Figure 5-1)” and “OHS relationship diagram (Figure 5-2)”. They compare the cost and OHS issues from these two latter diagrams and identify what is the importance rank of positioning two departments close to each other. Their reasons can be because of (1) being more cost efficient to locate the two departments closer, (2) it is safer to have the two departments further or closer to each other, and (3) other factors such as flow of information among the two departments affect their proximity. Accordingly, the safety-cost relationship diagram is prepared and based on that, the improved layout design will be portrayed.

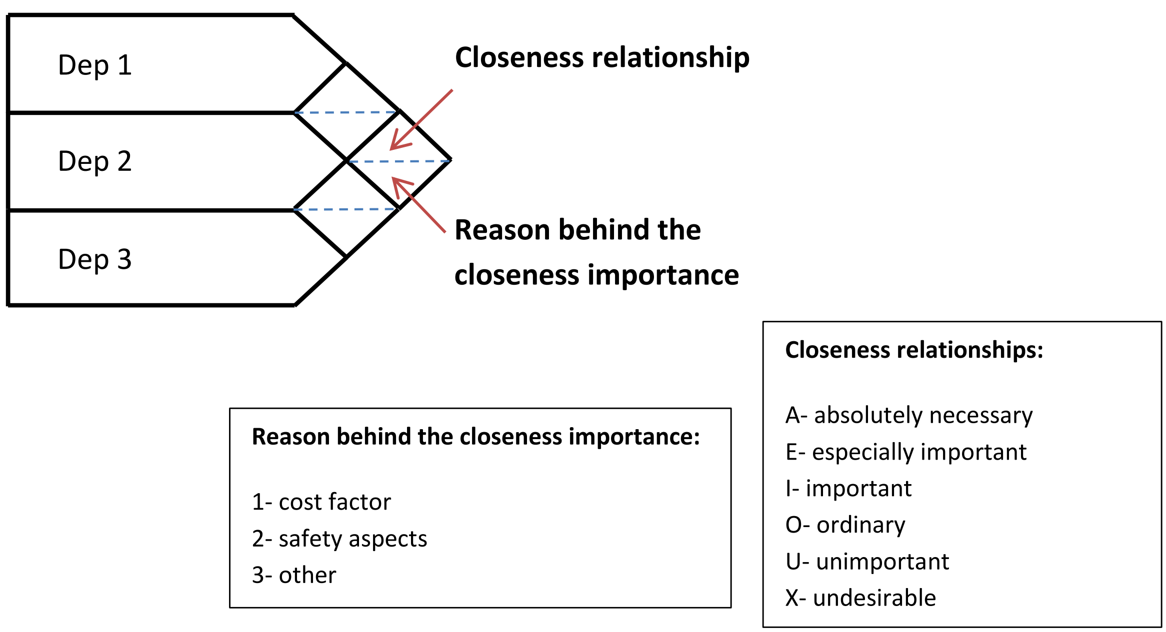

Figure 5-3: Safety-cost relationship diagram

To obtain an improved layout design, exchanges of departments should be considered. It is to make improvements by exchanging pairs of departments iteratively until no further improvement is possible.

In this regards, the material handling and transportation cost matrix should be designed for the new layout and the total cost value be calculated by using Eq. (1). The total cost value of the new layout is compared with the initial layout. If the cost value is lower for the new layout, it is determined that the new layout is our final layout improvement.

In the situation when the total cost value of the new layout is higher than the initial layout, exchanging pairs of departments must be considered. In this regards, the OHS relationship diagram (Figure 5-2) should be used. In this diagram, the department pairs with the lowest risk rank are considered as candidates for being exchanged. The risk value among these departments is low; hence it is not critical to reposition them for creating a new layout.

After exchanging locations of these departments, changes in the total cost value are determined. If exchanging of departments yields to a lower cost value, the exchange is made, which constitutes iteration. Exchanging is repeated until no further cost reduction is possible, while the safety concerns of positioning the departments close together must not be undermined either. Figure 5-4 summarizes this procedure.

5.5 Benefits and Restrictions of the Integrated Model

The proposed model uses an existing layout or a ‘from-to’ chart as input data for the flow cost. It measures the ‘risk values’ to evaluate the OHS aspects. These two factors can be used in agreement with each other when developing a layout. Including safety in the facility planning model leads to considering OHS in the facility as early as designing its layout, therefore reducing the chances of encountering with unsafe conditions triggered from layout design.

However, the improvements offered by the proposed model are not limited to designing a new facility layout. The model can also be applied to the current layout of an existing facility in order to ensure improvements with respect to OHS aspects. For this matter, the traditional approach of layout design is used for designing the facility layout with the material handling and transportation cost being the main factor in locating the departments. In order to adapt the layout with the OHS aspects, it can be modified by application of the 'Layout Improvements' steps of the proposed model.

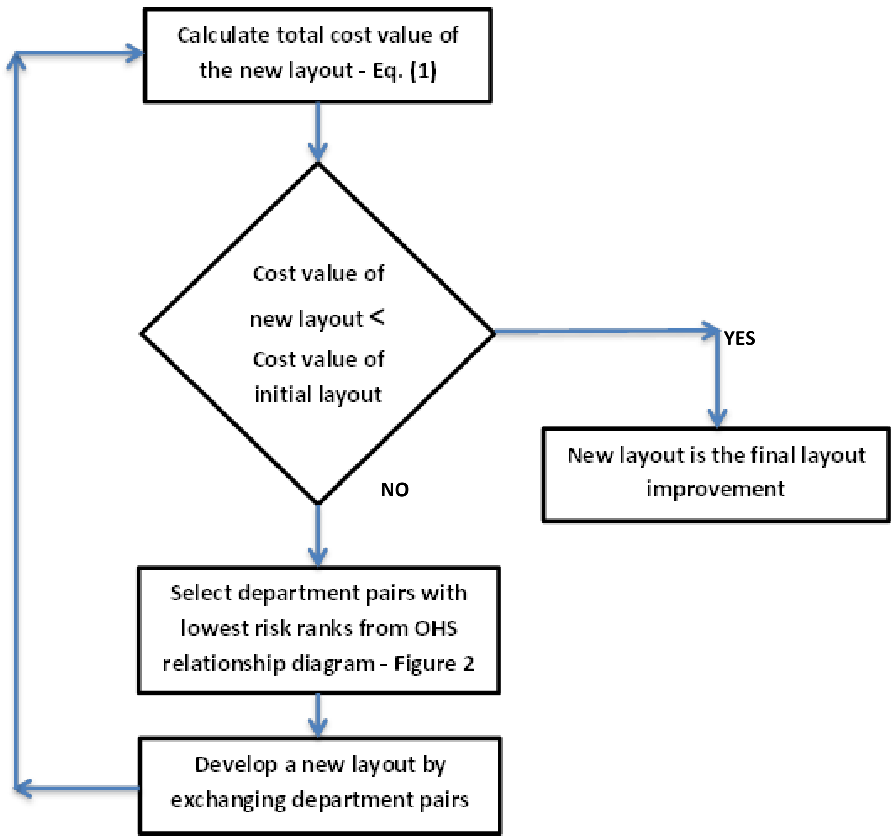

Figure 5-4: Layout improvements considering OHS aspects

Furthermore, the OHS aspects are considered quantitatively in this model, the safety relationships for locating departments are quantified. Proposed model can handle small to medium-sized problems because filling out each entry in the 'from-to' chart or assessing the risk scenarios would not be practical. It is an improvement-type methodology that may starts with an initial layout. Nevertheless, improvements in the layout are sought through department exchanges. The model follows a heuristic and does not guarantee an optimal solution. While searching for a better solution, the model picks only the best estimated exchange in each iteration. It also does not look back or forward during the above search. Such a solution is likely to be only locally optimal. Furthermore, the model is path-oriented and the final layout is dependent on the initial layout. Therefore, it is biased by its starting condition which is the initial layout.

The model is flexible in respect to the department shapes and as long as the department is not split, it is not restricted to rectangular departments. By using dummy extensions, the model can be applied to non-rectangular shapes. This may lead to irregular shapes both for individual departments and the plant layout itself.

There are also a few assumptions that should be considered for applying the model. The moving costs are not dependent on the equipment utilization. Besides, moving costs are linearly related to the length of the move. Moreover, if more than one hazardous situation (risk scenario) exists among two departments, the risk value for each scenario is calculated, and then the maximum values of those scenarios is considered as the risk value between the two departments. In such a case, the importance weight assigned to the risk value of scenarios is the same and equal to one.

5.6 Conclusion

Facility layout is one of the key areas which has significant contributions, in terms of cost and time, towards productivity in a manufacturing system. In developing facilities layout design, it is important to consider aspects such as the layout characteristics, material handling requirements, unit load implied, storage strategies, and the overall building impacts. Taking into account the human factor risks and OHS requirements are important issues, too. Specifically, it is imperative during the initial design phase of a new facility or in redesign and modification of an existing facility in order to give adequate considerations to OHS norms and to eliminate or minimize possible hazardous conditions within the work environment. Yet, incorporating safety during design makes economic sense because it is much cheaper to make changes during design than to negotiate change orders with a contractor or modify a facility after completion.

This research work explored how OHS should be included in the existing facility layout planning models. Therefore, the OHS aspects are considered as one of the essential factors to be considered in the design or modification of a facility layout. In this paper, facility layout planning models as well as those which integrate OHS were reviewed. In a previous study risk estimation tools were reviewed and a risk estimation tool was proposed, in which, the risk value is quantitatively measurable; hence easier to be merged into a facility planning model. Finally, a model is developed which embraces the concept of integrated OHS in facility layout design. This model chooses the best layout design according to both OHS aspects and material handling and transportation cost. Accordingly, facility designers can make decisions when the OHS aspects should take over the cost factor or vice versa.

Further research can evaluate the practicality of the proposed model in an existing facility or one in a layout design phase. In order to do so, Part II of the paper concentrates on application of the model to a layout design changes of the kitchen at a hospital, as real-world case study.

A detailed application of the present methodology may be found in Moatari-Kazerouni et al. (2014b).

Acknowledgments

We would like to thank NSERC for financial support.

CHAPTER 6 ARTICLE 3: INTEGRATION OF OCCUPATIONAL HEALTH AND SAFETY IN THE FACILITY LAYOUT PLANNING, PART II: DESIGN OF THE KITCHEN OF A HOSPITAL

Abstract[4]

Facility layout design has an important effect on the performance of manufacturing systems. It intends to determine relative location of departments and machines within a plant. A good layout design must ensure that a set of criteria and objectives are met and optimized, e.g., area requirements, cost, communication, and safety. The most common objective used in facility planning methods is to minimize the transportation cost. However, factors such as the plant safety, flexibility for future design changes, noise and aesthetics must be considered as well.

In this paper, a case study is carried out to investigate the safety concerns in facility layout design. In this regard, a facility layout planning methodology, integrating occupational health and safety (OHS) is presented. This methodology considers transportation cost as well as safety in the facility design. By this means, OHS issues are considered at the design stage of the facility. In other words, this research demonstrates the improvements in the layout design by integrating safety aspects.

Keywords: facility planning models, layout design, occupational health and safety (OHS), risk estimation

6.1 Introduction

Manufacturing systems are means of describing the combination of resources and methods inherent to manufacturing activities (Lefrancois and Montreuil, 1994). A manufacturing company is a complex human, machine, environment, and organization system. For productive and

[4] Moatari-Kazerouni, A., Chinniah, Y., Agard, B.; Integration of Occupational Health and Safety in the Facility Layout Planning, Part II: Design of the Kitchen of a Hospital; *International Journal of Production Research*; Status: Published Online (October 2014). DOI: 10.1080/00207543.2014.970711.

effective functioning of such companies, management should ensure optimum functioning of the system components. Although, there is a growing concern to improve productivity, safety, and quality in the manufacturing companies, many industries neglect facility design.

Plant layout deals with the arrangement of the most valuable assets of the companies, such as the departments and machines (Islier, 1998). It aims to obtain the most effective facility arrangements and minimize the material handling costs (De Alvarenga and Negreiros-Gomes, 2000). In other words, the facility designer attempts either to maximize an adjacency measure, minimize the total cost of material handling, or optimize some combination of the two (Kochhar et al., 1998). It is reported that the manufacturing industry is one of the most dangerous sectors for employees, given the frequency and severity of occupational accidents (Silvestri et al., 2012).

An improper workplace design, including poor human-machine system design, and problems with workstations, are common issues raised in manufacturing industries. These result in workplace hazards, poor workers' health, injuries linked to equipment, and disabilities (Shikdar et al., 2002). Occupational health and safety (OHS) regulations are aimed primarily at improving conditions in workplaces (Saari et al., 1993). They improve the performance of sub-standard companies as well as the initially safer companies. However, workplaces need to be compatible with the types of task to be conducted and human characteristics, so that risks to the health and safety of workers and the potential for human error is reduced to as low as reasonably practicable (Hadke and Gupta, 2013). At least 250 million occupational accidents occur every year worldwide which result in 335000 fatalities (ILO, 2012). OHS should be included in designing and modifying a facility. OHS contributes to product conformity, by ensuring that the conditions necessary for thoroughly carrying out tasks are met (De Oliveira Matias and Coelho, 2002). It will also result in a positive effect in promoting employees' productivity and quality of product or work; increase efficiency and productivity of the company and decrease costs.

Preventing OHS hazards is best achieved at the design stage of a facility layout. In order to have a good layout, it is important to promote safe and efficient operations, minimize travel time, decrease material handling, and avoid obstructing material and equipment movements (Karray et al., 2000). Methods like hazard analysis and risk assessment can be used for mitigating the risks to an individual at the workplace facility (Meswani, 2008). Potential hazards in the layout design must be identified. However, integrating OHS in facility planning in manufacturing industries has not been extensively studied and is often neglected by facility designers.

The main objective of this paper is to present a case study showing a facility layout methodology which integrates OHS. The case study is based on the real re-designing of the layout of a hospital kitchen in Montreal.

The next section presents the literature review, mainly focusing on the relationship between facilities layout design and OHS. Section 6.3 describes the research scope and contribution. Section 6.4 exposes the proposed methodology and the case study. The improvements that have been achieved will be discussed.

6.2 Literature Review

Studies have shown positive effects of applying OHS principles in companies. Nevertheless, the relationship between facilities layout design and OHS is not researched extensively. Broberg (2011) reports on the trial of the workspace design concept in a case involving the design and implementation of a new mixing technology in an industrial plant. Hadke and Gupta (2013) examine the employee’s workplace environment and evaluate the work performance at normal and abnormal condition at a nuclear power plant. They suggest how to optimize the situations in terms of work place design and optimize the work environmental parameters. Tam et al. (2004) examine the status of safety management in the Chinese construction industry, explore the risk-prone activities on construction sites, and identify factors affecting construction site safety. Hall-Andersen and Broberg (2013) researched on how companies respond to new safety regulations; while an engineering design case is analyzed using the theoretical concepts of boundary objects and intermediary objects. Benjaoran and Bhokha (2010) developed an integrated system for safety that incorporates safety measures into the design of plants. They formulated rule-based algorithms to help automatically identify hazards resulting from working at certain heights and advise proper safety measures. Aksorn and Hadikusumo (2008) identified and ranked 16 critical success factors of safety program implementation based on their degree of influence. Moatari-Kazerouni et al. (2014a) proposes a facility layout planning methodology which integrates the occupational health and safety features in the early design of a facility layout. The model considers transportation cost in the facility as well as safety concerns. Behm (2005) determined a link between fatalities and the design for construction safety by reviewing 224 fatality investigation reports. The research by Ho et al. (2010) aimed at better understanding the relationships between lean, the working environment, and its effects on employee health, job satisfaction, and commitment. Melzner et al. (2013) introduce an advanced design and planning approach for construction safety. It detects potential fall hazards and recommends safety protective equipment based on predefined rule sets. Kleban et al. (1996) developed a computer program that assists manufacturing engineers and environmental reviewers in assessing environmental consequences of their manufacturing decisions.

Shikdar and Sawaqed (2003) developed a computer software package as a self-assessment tool for evaluating ergonomic improvement potential of production systems by engineers, managers and safety professionals. Ergonomic conditions in small manufacturing industries are investigated by Shikdar and Al-Araimi (2001). Old machines, poorly designed workplaces, lack of systematic planning, layout and organization, unsafe working conditions and poor environment are commonly found in these industries. Neumannr et al. (2002) provide empirical evidence suggesting that production system design decisions, guided by technical considerations, result in negative ergonomic consequences.

The majority of previous research on facility layout design focused upon optimizing costs and closeness relations. Qualitative factors such as the plant safety, flexibility of layout for future design changes, noise and aesthetics must be considered as well.

6.3 Research Scope and Contribution

In Moatari-Kazerouni et al. (2014c), a risk estimation method was developed. In Moatari-Kazerouni et al. (2014a) the method for integrating OHS in facility planning using risk estimation was explained. In this paper, a case study which shows the integration of OHS in facility planning is presented. A new layout design for a hospital kitchen which not only would be cost efficient but also considers different safety issues existing in the current layout is developed. Relevant information for this study was gathered through observations and interviews with the kitchen personnel. Several observation sessions during various working hours of the kitchen were carried out. Interviews with the kitchen personnel shed light on existing safety concerns in the kitchen.

This layout design methodology would value OHS factors and consider their relative importance to cost when assigning locations to the various departments.

6.4 Integration of OHS in Facility Planning

6.4.1 Initial situation of the hospital

The case study was conducted in the kitchen of a hospital where the food is prepared, stored and distributed to every patient. The kitchen was originally design in 1907. Over time, different improvements and modifications were executed without an overall coordination. Recently, renovation of the kitchen layout was suggested to provide additional services such as the room service for supporting specific food requests at different times. The new concept of room service requires changes in the distribution and production areas. Different equipment had to be renewed and the facility layout had to be modified to satisfy the new concept. Therefore, changes in the layout design of the kitchen seemed necessary and the hospital has decided to update all the food service area.

A sketch of the current layout of kitchen is shown in Figure 6-1. The kitchen consists of different sections: office area, production area (food preparation), distribution centre including a conveyor and workstations for mounting food trays for patients, service area for weighing portions and selecting ingredients for recipes, section for pastries, area for washing the trolleys (used for transporting trays), area for dismounting the used trays collected from patients, area for washing the dishes and trays, storage and warehouse areas i.e., refrigerated rooms for perishables and storage room with racks for non-perishables items.

The current layout of the kitchen is mainly designed based on the flow of products (foods) throughout the facility as well as the efficient closeness of department according to the cost factor. There are safety issues in regards to the kitchen layout which require re-designing and changes in the location of different departments. These will involve the proposition of a new layout design based on not only the cost factor but also OHS issues. The methodology to integrate OHS in facility planning is elaborated in the following sections.

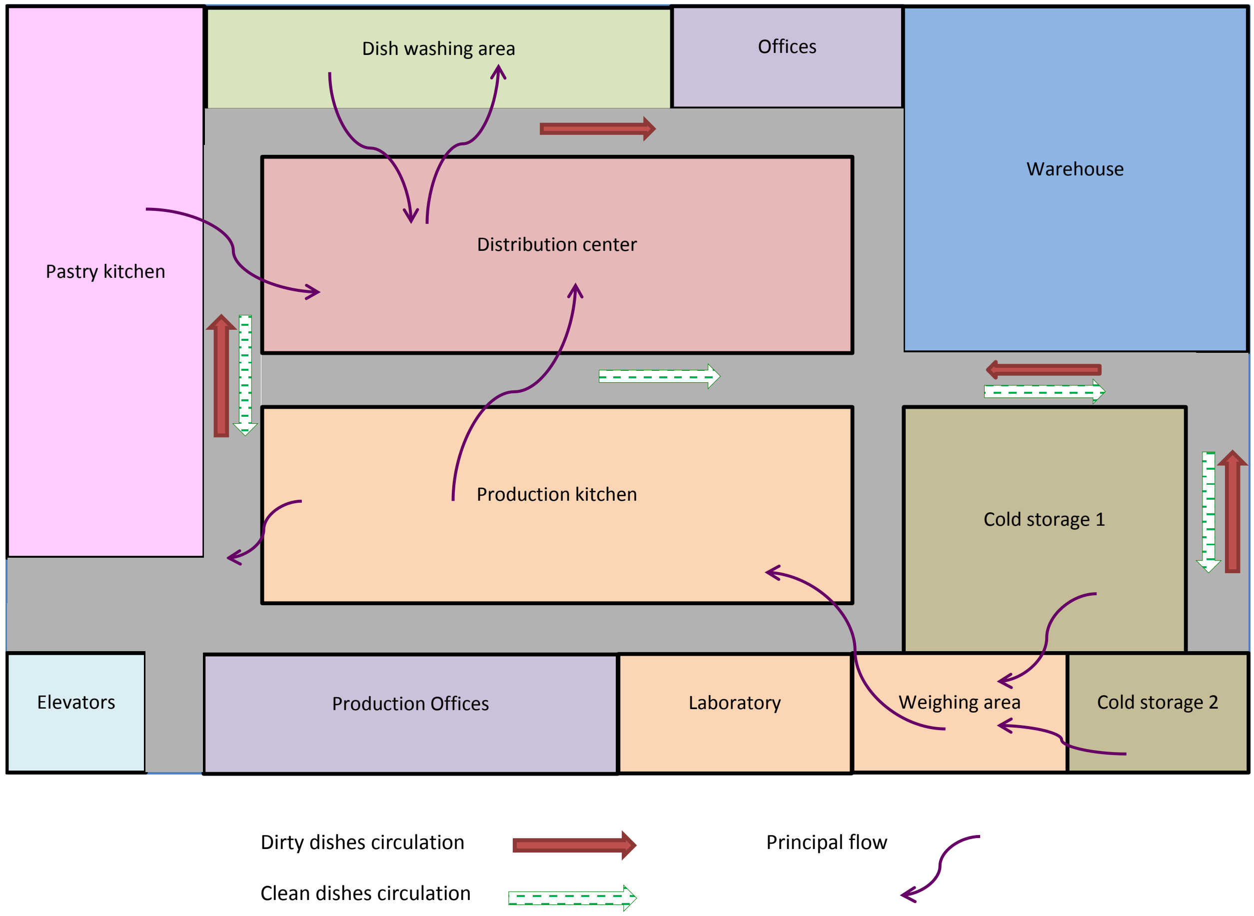

Figure 6-1: Current layout design of the kitchen

The kitchen has 12 departments and 9 hall ways. The total available space is considered to be 13000 ft^2, and the cost of carrying material per unit distance is one. The 'from-to' chart is as shown in Table 6.2. As an example, the flow from the "dish washing area" to "offices" department is 146 and 0 from the "offices" to "dish washing area".

The current layout of the kitchen has flaws from facilities layout and OHS points of view. The 'from-to' chart reveals the high transportation of product and services between "distribution centre" and the elevator as well as the "dish washing area" and the elevator. Therefore, locating the elevator to these two departments could be considered to reduce the material handling and transportation cost. In terms of OHS, material handling between the "distribution centre" and "production kitchen" can lead to hazards.

6.4.2 Methodology for Integrating OHS in Facility Planning

Muther (1973) developed a layout design procedure named as Systematic Layout Planning (SLP). This process is widely used by engineers for facility planning projects and involves optimizing three fundamental aspects of relationships, space, and adjustment. In SLP process, based on the input data and an understanding of the roles and relationships between activities, a from-to chart and an activity relationship chart are probed; consequently a relationship diagram is developed. Considering the space required and the available space, a space relationship diagram is configured. Based on the modifying considerations and practical limitations, a number of layout alternatives are developed and evaluated. The preferred layout is then identified and recommended (Tompkins, 2010). The methodology presented in this paper is partly based on the relationship diagramming process presented in the SLP process.

The methodology, explained in detail in Moatari-Kazerouni et al. (2014a) consists of three steps. First step concentrates on the traditional cost factors. The cost matrix is calculated by multiplying "number of loads from the 'from-to' chart" by "rectangular distance between departments from the distance matrix" by "cost per unit distance". Five cost categories are defined according to their relative cost portions. Applying these categories, the relative importance in closeness of the departments based on the cost factor, is demonstrated as a cost relationship diagram.

The second step evaluates layout design by considering OHS aspects. Risk scenarios need to be identified. For these scenarios, quantitative levels of the five risk parameters is evaluated, i.e., severity of harm, frequency of exposure to the hazard, duration of exposure to the hazard, probability of occurrence of a hazardous event, and technical and human possibility of avoiding or limiting the harm. For each scenario, the risk value is calculated (Eq. 2) and the safety relationship diagram is designed.

The third step explains how the former layout can be adjusted based on the OHS aspects by using the safety-cost relationship diagram. The layout is improved by exchanging the positions of departments. The department pairs with the lowest risk rank are considered as candidates for being exchanged. As a result, the layout design is improved by including OHS aspects. This is assured by determining changes in the total cost value of layout.

In designing a new layout, this methodology suggests considering cost factor, followed by the safety aspect. Details of each step of the model are explained throughout the case study example in the following paragraphs.

6.4.2.1 Step 1- Material Handling and Transportation Cost Factor

A) Develop the distance matrix by calculating the distance between departments. The distance matrix for the case study is shown in Table 6.2.

B) Calculate cost matrix by multiplying "flow of material from the 'from-to' chart" by "distance from the distance matrix" by "cost of carrying any material".

The cost matrix for the case study is calculated by multiplying Table 6.2 by Table 6.3 and is illustrated in Table 6.4.

C) Calculate the total cost value by using Eq. (2).

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} d_{ij} c_{ij} \tag{2}$$

where, i and j are the departments, m is the total number of departments, f_{ij} is the flow of material from the 'from-to' chart, d_{ij} is the distance from the distance matrix, and c_{ij} is the cost of carrying any material.

The total cost value for the case study equals to $ 113 795.

D) Define the five cost categories according to their relative cost portions, where category 5 contains the highest cost values and category 1 the lowest; corresponding to Table 6.1.

Table 6.1: Cost categories

Cost Categories	Ranks	Cost Portions %
Category 1	U- unimportant	< 50%
Category 2	O- ordinary closeness	> 40%
Category 3	I- important	> 25%
Category 4	E- especially important	> 12%
Category 5	A- absolutely necessary	> 5%

The cost matrix table is upper-triangle and color-coded based on the different categories identified in Table 6.1 and is demonstrated in Table 6.5.

Table 6.2: ‘From-to’ chart of the kitchen

From/To	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		0	100	120	230	200	90	10	50	210	30	10
dish washing area	146		197	40	381	160	30	300	95	43	0	0
warehouse	197	20		210	87	315	0	106	0	164	0	0
pastry kitchen	51	270	321		380	130	90	100	20	63	14	0
distribution centre	159	396	20	11		48	270	397	35	134	0	120
production kitchen	103	195	16	183	379		294	84	30	142	22	17
cold storage 1	18	56	0	81	215	200		97	61	32	282	0
elevators	10	350	362	347	295	67	133		14	19	0	75
laboratory	39	160	0	0	195	244	32	0		51	0	0
production offices	81	0	161	0	239	270	99	0	17		16	0
weighing area	15	110	0	67	33	202	0	0	0	0		0
cold storage 2	0	190	0	51	70	77	0	0	0	0	219	

Table 6.3: Distance matrix of the kitchen

Distance	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		3	5.75	9.25	4.5	8.25	10.25	14.75	9.5	12.25	11.25	14.5
dish washing area	3		8.75	6.25	3.5	7.25	13.25	11.75	11.5	9.25	14.25	17.5
warehouse	5.75	8.75		11.5	6.75	10.5	5	17	11.75	14.5	7	6.75
pastry kitchen	9.25	6.25	11.5		4.75	6	12	5.5	10.25	7.5	13	16.25
distribution centre	4.5	3.5	6.75	4.75		3.75	9.75	10.25	8	7.75	10.75	14
production kitchen	8.25	7.25	10.5	6	3.75		6	6.5	4.25	4	7	10.25
cold storage 1	10.25	13.25	5	12	9.75	6		12	6	8.75	4	4.25
elevators	14.75	11.75	17	5.5	10.25	6.5	12		5.25	2.5	8	11.25
laboratory	9.5	11.5	11.75	10.25	8	4.25	6	5.25		2.75	2.75	6
production offices	12.25	9.25	14.5	7.5	7.75	4	8.75	2.5	2.75		5.5	8.75
weighing area	11.25	14.25	7	13	10.75	7	4	8	2.75	5.5		3.25
cold storage 2	14.5	17.5	6.75	16.25	14	10.25	4.25	11.25	6	8.75	3.25	

Table 6.4: Cost matrix of the kitchen

Cost Matrix	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices	0	0	575	1110	1035	1650	922.5	147.5	475	2572.5	337.5	145
dish washing area	438	0	1723.8	250	1333.5	1160	397.5	3525	1092.5	397.75	0	0
warehouse	1133	175	0	2415	587.25	3307.5	0	1802	0	2378	0	0
pastry kitchen	471.8	1687.5	3691.5	0	1805	780	1080	550	205	472.5	182	0
distribution centre	715.5	1386	135	52.25	0	180	2632.5	4069	280	1038.5	0	1680
production kitchen	849.8	1413.75	168	1098	1421.25	0	1764	546	127.5	568	154	174.25
cold storage 1	184.5	742	0	972	2096.25	1200	0	1164	366	280	1128	0
elevators	147.5	4112.5	6154	1908.5	3023.75	435.5	1596	0	73.5	47.5	0	843.75
laboratory	370.5	1840	0	0	1560	1037	192	0	0	140.25	0	0
production offices	992.3	0	2334.5	0	1852.25	1080	866.25	0	46.75	0	88	0
weighing area	168.8	1567.5	0	871	354.75	1414	0	0	0	0	0	0
cold storage 2	0	3325	0	828.75	980	789.25	0	0	0	0	711.75	0

Table 6.5: Cost matrix of the hospital kitchen based on the cost categories

Cost Matrix	offices	dish washing area	warehouse	pastry kitchen	distribution centre	production kitchen	cold storage 1	elevators	laboratory	production offices	weighing area	cold storage 2
offices		438	1707.75	1581.75	1750.5	2499.75	1107	295	845.5	3564.75	506.25	145
dish washing area			1898.75	1937.5	2719.5	2573.75	1139.5	7638	2932.5	397.75	1567.5	3325
warehouse				6106.5	722.25	3475.5	0	7956	0	4712.5	0	0
pastry kitchen					1857.25	1878	2052	2459	205	472.5	1053	828.75
distribution centre						1601.25	4728.75	7093	1840	2890.75	980	2660
production kitchen							2964	981.5	1164.5	1648	1568	963.5
cold storage 1								2760	558	1146.25	1128	0
elevators									73.5	47.5	0	843.75
laboratory										187	0	0
production offices											88	0
weighing area												711.75
cold storage 2												

E) Demonstrate the relative importance in closeness of the departments based on the cost factor by illustrating a cost relationship diagram. Figure 6-2 shows the cost relationship diagram for the current layout of kitchen (Moatari-Kazerouni et al., 2014c).

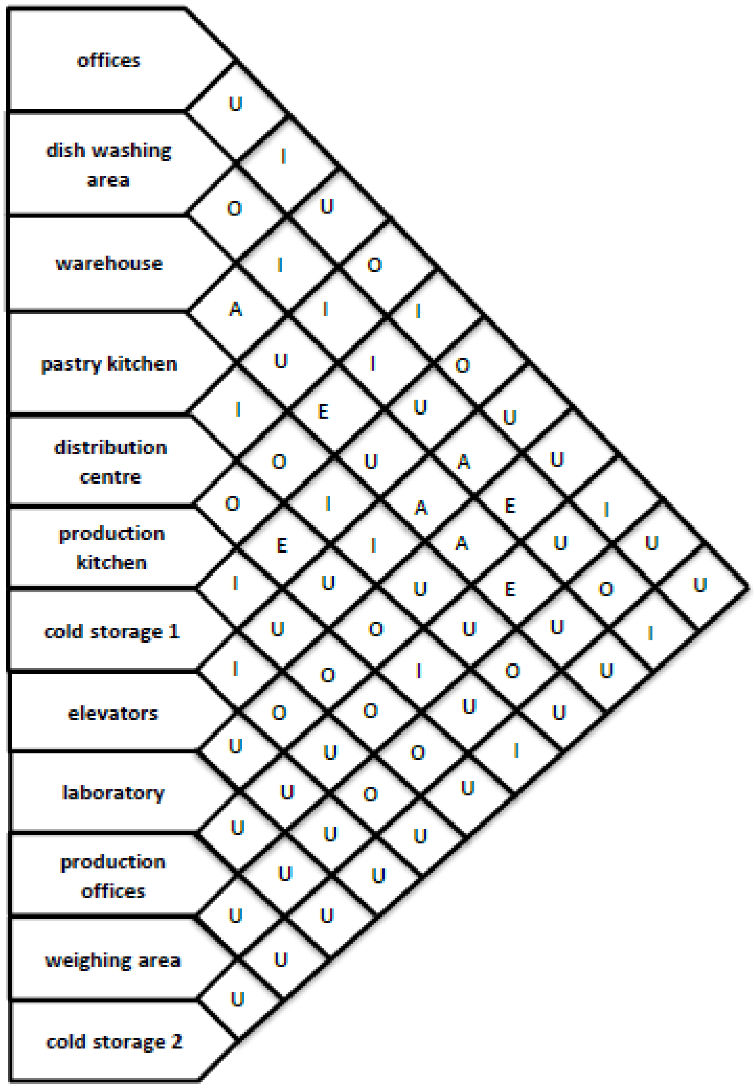

Figure 6-2: Material handling and transportation cost relationship diagram

6.4.2.2 Step 2- OHS Evaluation

F) Develop risk scenarios for the initial layout design.

Four risk scenarios are identified in the initial layout of hospital kitchen.

Scenario 1: The first scenario indicates the noise hazard which would be considerable when the "offices or production offices" and "dish washing area" departments will be located close to each other. The hazard is from the noise caused by the dish washing conveyor and the noise generated by the metallic utensils. It can be very disturbing for the office workers in continuous exposure.

Scenario 2: Interruptions in the material handling between the "distribution center" and "production kitchen" departments is a movement hazard which can be a danger for workers, e.g., while carrying boiling water one stumbles upon or collide with another worker.

Scenario 3: The dish washing machine generates a lot of heat. It can be harmful for the worker specifically those who work at the cold storage area. A sudden temperature change from the extreme cold (in the cold storage area) to the hot temperature (of dish washing and dryer machine) is a hazard for workers. This heat hazard is considerable when the "dish washing area" and "cold storage 1 or 2" departments are located close together.

Scenario 4: Chemicals are stored in the warehouse; therefore, fumes are possible from chemicals being in contact with heat generated in the production and distribution area. This indicates the chemical hazard between "warehouse" and "distribution center or production kitchen" departments.

- **G)** For each hazardous situation, identify the qualitative risk level for each of the five risk parameters as addressed in Moatari-Kazerouni et al. (2014c). These parameters, which were identified through an extensive literature review, are namely: (1) severity of harm, (2) frequency of exposure to the hazard, (3) duration of exposure to the hazard, (4) probability of occurrence of a hazardous event, and (5) technical and human possibility of avoiding or limiting the harm. Since the proposed risk parameters are qualitatively scaled, they were transformed into quantitative measures. A rating system is used by which quantitative values (1-5) are assigned to the levels of each risk parameter.
- **H)** For each hazardous situation, calculate the risk value:

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

I) For each risk scenario, identify the corresponding interval for the risk value according to the conversion table (Risk value evaluation) proposed in Moatari-Kazerouni et al. (2014a).

Since the maximum number obtained from the aforementioned equation is 125 and the minimum is 1, in this paper the range of risk ranks were divided to 5 equal categories from 1 to 125. However, designers can adjust the risk categories to reflect the realities of the manufacturing plants and their preferences for tolerable risk. These categories are ranked by scales of 1 to 5. A higher risk value indicates that it is dangerous to place the departments close to each other.

The evaluation of scenarios for this case study is shown in Table 6.6. This estimation is based on the observations of different tasks carried out in the kitchen.

Table 6.6: Scenario analysis

	S	Ph				Risk Value	Safety Ranks
SCENARIOS		**Exf**	**Exd**	**Pe**	**A**	**R=S*(Exf+Exd+2*Pe+A)**	
Scenario 1	4	5	5	3	4	**80**	2
Scenario 2	4	5	5	3	5	**84**	2
Scenario 3	2	5	5	3	4	**40**	4
Scenario 4	5	5	5	4	4	**110**	1

J) Demonstrate the relative importance in closeness of the departments based on the safety factor as a safety relationship diagram.

Figure 6-3 illustrates the OHS relationship diagram for the current layout of kitchen (Moatari-Kazerouni et al., 2014c).

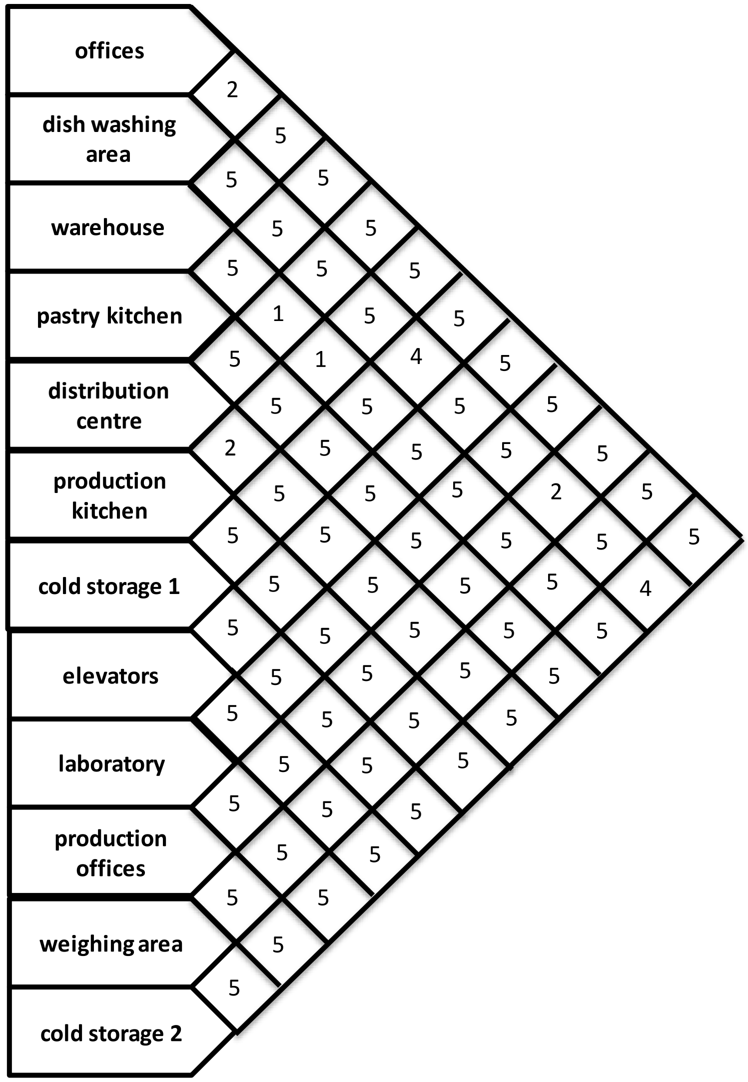

Figure 6-3: OHS relationship diagram

6.4.2.3 Step 3- Layout Improvements Considering OHS Aspects

K) Design a safety-cost relationship diagram.

As it is mentioned previously, this methodology considers cost factor, followed by the safety aspect for choosing the department-pairs to enter the layout. Other issues such as the priorities set by the company or the facility planner's opinion can also influence the choice.

By comparing the ranks assigned to cost (Figure 6-2) and safety (Figure 6-3) factors, the safety-cost relationship diagram for the current layout of kitchen is illustrated in Figure 6-4. See Moatari-Kazerouni et al. (2014c) for more details.

The closeness relationships between (1) “office” and “dish washing area”, (2) “warehouse” and “distribution centre”, (3) “warehouse” and “production kitchen”, (4) “dish washing area” and “cold storage 1”, and (5) “dish washing area” and “production offices” are changed because of the safety factor. For these departments, the ranks assigned to the OHS issues were more important than the cost factors. Therefore, the closeness relationships are decided based on the safety reasons.

For the closeness relationship among “dish washing area” and “cold storage 2”, both safety and cost factors are important. However, the rank assigned to the cost factor was higher than the OHS concerns. Therefore, the closeness relationship between these two departments is determined according to the cost reason.

Furthermore, the relationship between the “offices” and “warehouse” is set because of the management point of view. There is a high flow of information between these two departments. Therefore, locating them closer together can be beneficial.

For the rest of the departments, the closeness relationships are grounded because of the cost reason, since the ranks are higher for the cost than the safety factors.

- **L)** Design a new layout based on the safety-cost relationship diagram (Figure 6-4).
- **M)** Make improvements by exchanging pairs of departments iteratively until no further improvement is possible.

In this concern, total cost value of the new layout should be calculated based on Eq. (2). If the cost value for the new layout is less than the cost of initial layout, new layout is the final layout improvement. Otherwise, department pairs with the lowest risk rank from OHS relation diagram will be selected. A new layout will be developed by exchanging these department pairs and the cost value will be calculated again.

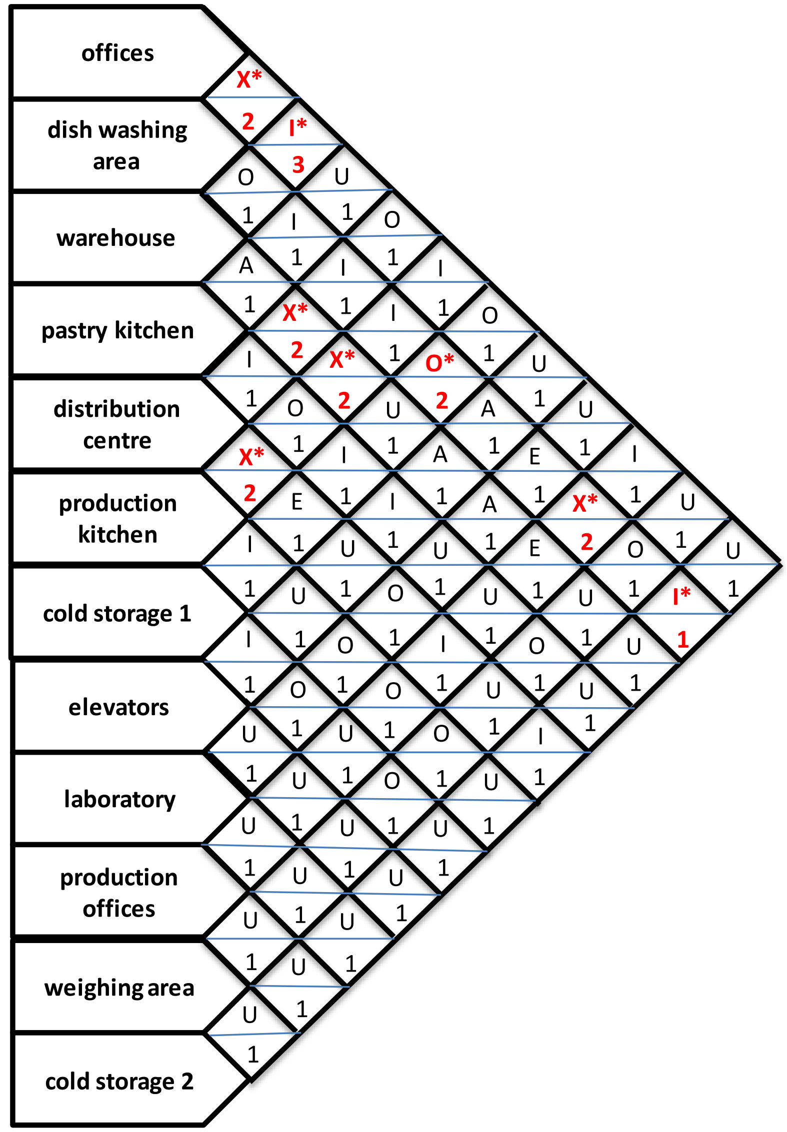

Figure 6-4: Safety-cost relationship diagram

The new layout suggested for the kitchen is shown in Figure 6-5. This layout is designed based on the safety-cost relationship diagram and consider OHS issues as important as the cost efficiency objective. In this layout the location of the “dish washing area” is changed by the “offices”, while “production offices” is switched by the “laboratory” department. In this new layout design, the “offices” are located further from the “dish washing area” because of the undesirable closeness relationship (X) among them due to the safety issues (Scenario 1). However, the “offices” department is still enough close to the “warehouse” to satisfy their important closeness relationship (I) in regards to the flow of information among them. Changing the location of the “dish washing area” also increased the distance among “dish washing area” and “cold storage 1 or 2” departments. This further distance among the “dish washing area” and “cold storage 1 or 2” departments improves the temperature differences between these departments and decreases the heat safety concerns of Scenario 3.

The total cost value for this new layout is calculated as $ 110 196 which is less than the initial layout cost. Hence, the new layout based on the safety and cost factors is an improvement to the current layout of the kitchen.

It should be mentioned that this new layout is just one example of the possible improved layout designs for our case study. Iterating the steps of the proposed model can lead to other layout designs.

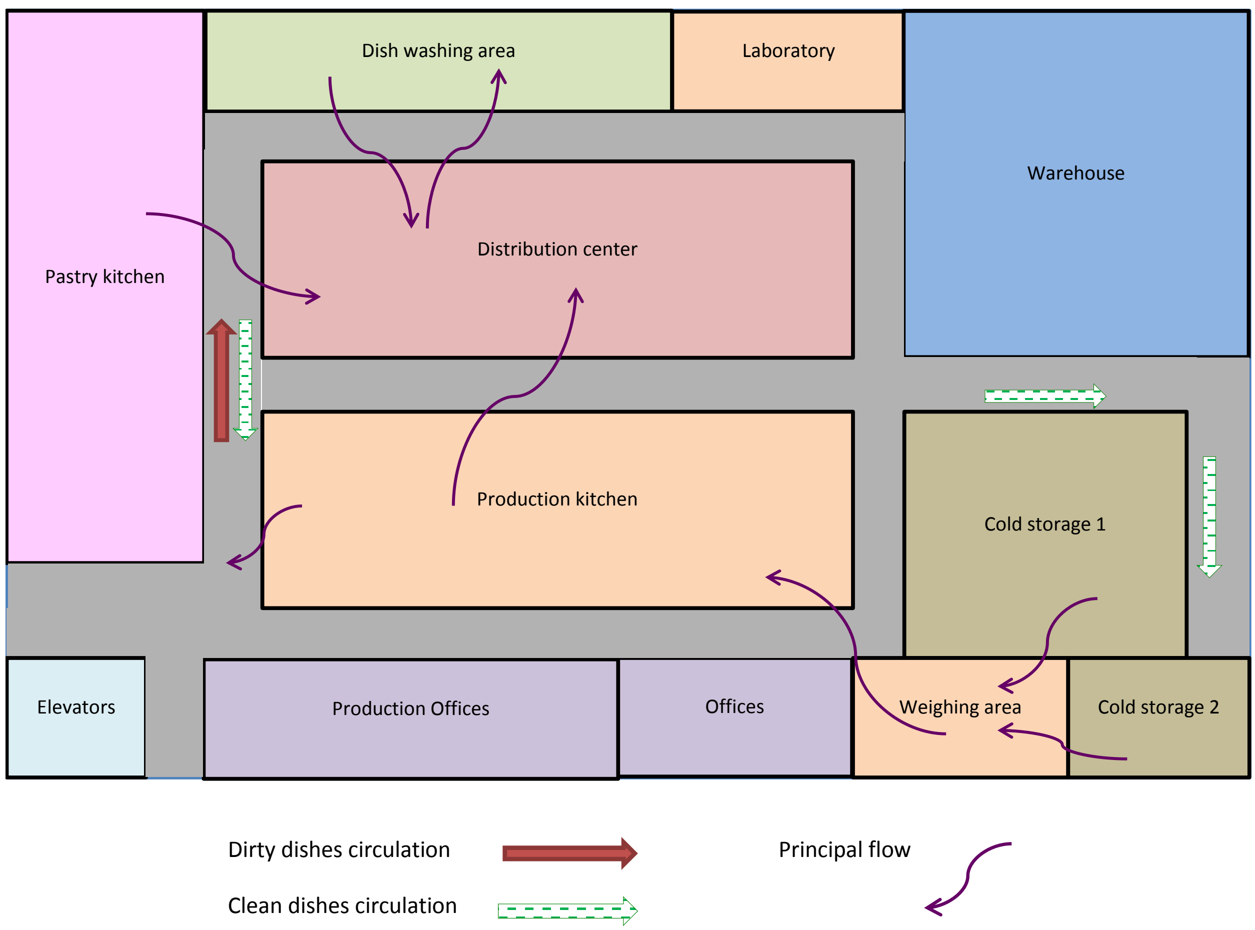

Figure 6-5: New layout design of the kitchen

6.5 Discussion

The layout design changes of the kitchen at the hospital were proposed to ultimately replace the old facility, designed in 1907. The new layout is aimed to be able to serve more clients (patients) while supporting additional services such as room services. The new layout design that is proposed in this paper not only covers these purposes but also suggest a layout which improves the occupational health and safety for the personnel and their working environment. A comparison between the new layout and the old one is presented in Table 6.7. Current layout of the kitchen is compared to the proposed layout design in regards to OHS issues, cost and other important factors.

Concerning the four safety scenarios, changes in the new layout design has improved the OHS issues for Scenario 1 by changing the location of the “dish washing area” and “offices” (Scenario 1). In addition, locating the “dish washing area” further from “cold storage 1 or 2” departments has improved the OHS issues for Scenario 3. Changes in locations of departments did not have any significant OHS difference for the other two scenarios. However, re-applying the methodology could result in further safety improvements.

The total cost of developing the layout decreases for the proposed layout design comparing to the old one. However, considering that the kitchen already exist, re-designing of its layout require cost of design changes.

The total available space is considered to be fixed (13 000 ft^2) for developing the new layout design; while, the proposed layout improved the possibility of preparing more food (meal request) as well as offering additional services to the patients and their visitors.

Furthermore, the working condition and environment is enriched for the kitchen personnel in regards to the OHS issues, whereas the human factor risks are decreased in the new layout design. Besides, the location of “offices” and “warehouse” departments are enough close to each other to improve the communications between these two departments.

Therefore, the new layout design, which concurrently considers OHS and cost factors, is an improvement to the current layout of the kitchen.

Table 6.7: Comparison of old and new layout designs

		Old Layout Design	**New Layout Design**
OHS Factor	Scenario 1	**2** (safety rank)	**I**
	Scenario 2	**3**	**NC**
	Scenario 3	**4**	**I**
	Scenario 4	**1**	**NC**
Cost Factor	Total cost of layout design	**$ 113 795**	**$ 110 196**
	Cost of design changes		**D**
Other	Space requirements		**NC**
	Number of product units		**I**
	Clients services		**I**
	Personnel working condition/environment		**I**
	Flow of information		**I**

Legend: **NC- no change** **I- improvement** **D- deterioration**

6.6 Conclusion

Facilities layout design is an important industrial issue as it directly and indirectly results in higher efficiency of the system. A practical layout design should meet multiple objectives rather than a single one (e.g., material handling cost); multiple objectives models for layout design, especially qualitative objectives such as safety, require further research. In an effort to improve the facility layout planning models, this paper investigated how facility planning models and risk estimation tools can be improved and integrated in order to provide a more robust method that can better meet productivity and safety requirements. A case study involving a kitchen of a hospital is presented.

Acknowledgments

We would like to thank NSERC for its financial support.

CHAPTER 7 GENERAL DISCUSSION

This dissertation is aimed to answer two sets of research questions. The first question proposes a risk estimation methodology to quantitatively measure the risk value for different OHS hazardous events. To respond to the second research question an integrated approach is considered for modifying a facility planning model to include the proposed risk estimation methodology. The new facility planning model is evaluated through a case study. The following sections will discuss the research results with regards to these three areas of contribution.

7.1 Risk Estimation Tool for Manufacturing Systems

Several risk estimation tools are proposed in literature. These tools are used to estimate the risk degree of different hazardous events. The risk parameters and number of levels that are considered in these tools varies. The need for having a risk estimation tool which is applicable in different OHS areas, while it is comprehensive in regards to the risk parameters and levels, appeared to be essential. In order to satisfy this need and have a risk estimation tool which can facilitate the integration of OHS into facility planning models, a new risk estimation tool is proposed.

The 31 tools are studied in detail in regards to their risk parameters, levels, and how they calculate risk. This number is narrowed down to five tools which numerically calculate risk. The new tool is developed that uses the severity (S) of harm as well as the probability of occurrence of harm (Ph), which consists of: frequency of exposure to the hazard (Exf), duration of exposure to the hazard (Exd), probability of occurrence of a hazardous event (Pe), and technical and human possibility of avoiding or limiting the harm (A). For each of these parameters, five risk levels are identified. This tool calculates the risk value using these parameters in a numerical approach.

Furthermore, the proposed risk estimation tool is applies to 20 hazardous scenarios in order to compare the results from this new tool with the 31 other tools. Not all these risk scenarios are necessarily in concern with the layout design. These scenarios are selected to only evaluate the performance of the proposed risk estimation tool, while they may not demonstrate applicability of the tool for safety issues among departments or work stations of a facility.

The results state that the new tool very similarly evaluates the risk assigned to 20 scenarios comparing to the original risk assignments. Moreover, there is a correlation between the structure of new tool and the other risk estimation tools.

The contributions of the proposed risk estimation tool includes: functioning similarly to other well-known risk estimation tools, being applicable to different industries and OHS hazards, comprehensive in terms of risk parameters and their levels, following a numerical approach in calculating risk while it is a pseudo-quantitative tool. Moreover, the proposed risk estimation tool is designed as a first step for integration into facility planning models.

7.2 Integrating OHS in Facility Layout Planning

Facility planning and layout design has been studies extensively in the past decades. Different approaches and model are proposed for designing the layout of a facility. However, the main two objectives in layout design have always been cost efficiency and adjutancy; while OHS concerns are often overlooked in locating different departments and machines inside a facility. Integrating OHS in facility layout design assures a safer working environment for the workers and can decrease costs associated with accidents and incrustations initiating from poor layout designs.

The objective of this part of the research is to introduce a facility planning model which considers safety as important as the cost factor. To achieve this objective, the proposed risk estimation tool is incorporated in the traditional approach of designing a facility layout and a model for integrating OHS in facility planning is proposed.

The proposed facility planning model consists of four steps. The first step concentrates on the cost factor and calculates the material handling and transportation cost by multiplying “from-to chart” by “distance matrix” by “cost per unit distance”. A material handling and transportation cost relationship diagram is illustrated to show the relative importance in closeness of the departments based on the cost factor.

The second step concentrates on incorporating OHS in the model by means of the proposed risk estimation tool (Moatari-Kazerouni et al., 2014c). Therefore, the current design of the facility should be investigated for finding different hazardous situations and safety scenarios. This could be done by using the checklist (Moatari-Kazerouni et al., 2012). Then, the proposed risk estimation tool is applied to these scenarios and a quantitative risk value is assigned to them.

Similar to cost factor, the relative importance in closeness of the departments based on the safety factor is demonstrated in a safety relationship diagram.

The third step proposes how the departments should be located in the layout when considering the cost factor; while the forth step considers layout improvements based on the OHS aspects. To do that, the cost and safety relationship diagrams are compared. A safety-cost relationship diagram is created in which the facility planning group identify the importance rank of positioning two departments close to each other based on being (1) cost efficient, (2) safer, or (3) other factors such as better flow of information. Exchange of departments should be considered in different iterations to produce new layouts. If the total cost value of the new layout is higher than the initial one, OHS relationship diagram is used in exchanging the department pairs with the lowest risk rank.

Therefore, a facility planning model is developed which embraces the concept of integrated OHS in layout design. It can be applied to small to medium-sized. One of the advantages of this model is that not only it can design a layout for a new facility, but also it is functional for a current layout of an existing facility in order to ensure improvements with respect to OHS. Besides, OHS aspects are considered quantitatively in this model.

7.3 Case Study in Designing a Safer Kitchen for a Hospital

In order to assess the integrated facility planning model (Moatari-Kazerouni et al., 2014a), a case study is carried out at the kitchen of a hospital. It is considered as an application in a manufacturing setting. The kitchen is reasonably old while improvements are required in its production line. The integrated facility planning model is implemented to provide a new layout design for the kitchen and improve safety for the workers. Information is gathered via observations and interviews with kitchen personnel.

Initial situation of the kitchen is evaluated by configuring the cost matrix and the material handling and transportation cost relationship diagram. In addition, four risk scenarios are identified in the initial layout of hospital kitchen. These scenarios highlighted the risks associated with the noise, movement, heat, and chemical hazards. The proposed risk estimation tool is applied to each risk scenario and results were illustrated in the OHS relationship diagram.

The safety-cost relationship diagram is designed to initiate the layout improvement process. Repositioning the departments in the new layout design is resulted in improvements in regards to the noise and heat hazards. The total cost of developing the layout decreases for the proposed layout design. However, the model should be re-applied and more iterations of layout suggestions needs to be evaluated which could result in further safety improvements.

The working condition and environment is improved for the personnel working in the kitchen. With the new layout design, they benefit from a safer work environment, whereas the human factor risks are decreased.

7.4 Research Contributions

Three areas of contributions can be discussed concerning the research work of this dissertation.

7.4.1 Methodological contribution

As the methodological contributions, a risk estimation tool and an integrated facility planning model is proposed in this dissertation. Both of these models have similar theoretical foundation to other approaches in literature and the practitioner does not require understanding the underlying theory. Thus, even though these models bring up methodological contributions to previous risk estimation and facility planning approaches, they are easy to use.

7.4.2 Theoretical contribution

This research has contributed theoretically to the literature by two means. Firstly, an improved risk estimation tool is proposes. The contribution of this tool is by taking into account the six risk parameters. The flaws identified in previous study regarding risk estimation tools were taken into consideration when the new tool was designed. Introducing detail risk levels for these parameters while numerical ranks are assigned to them should be named as another theoretical contribution. Most of the risk estimation tools evaluate the risk qualitatively. The proposed risk estimation tool offers a formula to quantitatively measure the risk value.

The second theoretical contribution of this dissertation is in presenting a facility planning model in which OHS aspects are integrated. The main objective of facility layout design approaches have usually been decreasing the cost or increasing the adjutancy. Safety aspects did not receive much attention. The integrated facility planning model of this dissertation sheds light on different OHS aspect which should be considered in designing the layout in order to improve the working environment for the workers. In this mode, safety and cost are the two main factors in deciding the position of different departments and machines. Therefore, the theoretical contributions of this model are in including OHS aspects vs. only ergonomic factors, as well as considering cost and safety aspects at a similar level.

7.4.3 Practical contribution

The practical contribution of the proposed models can be highlight by their applicability to any industrial sector, from manufacturing to service and healthcare settings. While the application of the integrated facility planning model is demonstrated in the hospital kitchen case study in this dissertation, implementing this model in a complex industrial system (e.g., production line of an aerospace company) or at a service sector (e.g., the operating room of a hospital) is possible.

7.5 Research Limitations

One of the main limitation of this research initiates from application of the case study. Implementing the proposed integrated facility planning model in different industrial and service sectors could better strengthen its applicability in various settings.

Moreover, in evaluating the risk estimation tool, the risk scenarios are mostly taken from the manufacturing sector; while testing the model in regards to the hazardous scenarios from services sector can be stimulating. These risk scenarios may not be relevant to layout design. Evaluating the proposed tool with the facility design related safety issues should be considered as well.

The improved risk estimation tool is proposed based on safety of machinery philosophy. The tools used to estimate the risk associated with hazards such as MSDs, noise, or harmful substances need to be considered as well.

In applying the integrated facility planning model, several practitioners needs to participate in identifying the OHS hazardous scenarios, assigning risk ranks, as well as making decisions on repositioning the departments and machines. This requirement could restrict the credibility of results when the model is applied by only one practitioner. In addition, analysing the proposed steps could require more time than other simpler existing approaches.

Additionally, the proposed integrated facility planning model follows a heuristic and does not guarantee an optimal solution.

7.6 Research Perspectives

Throughout this PhD research, a facility layout planning model is developed which integrates the OHS features in the early design of a facility layout. The proposed methodology considers the transportation cost in the facility as well as safety concerns. By this means, the regulatory, safety, and ergonomics issues are reflected prior to the construction of a facility.

In order to solve this integrated facility layout model, developing and using conventional algorithms and techniques for this model is suggested as future research. By this means, a heuristic method is developed and used in order to design a layout adapted to minimum material handling cost, as well as amended with OHS of workers. A safe layout created by heuristic method can accommodate considering OHS in the facility as early as designing its layout, therefore reducing the chances of encountering with problems from unsafe conditions triggered from layout design. Furthermore, simulation modelling can be used to demonstrate the application of the proposed model in this dissertation. Different mathematical and algorithmic approaches for solving FLP were presented in Chapter 1. Using the structure of these approaches, the proposed integrated facility planning model can be formulated mathematically. By this means, the iterations in developing layout designs can be generated and compared easier.

Applying the research in different industrial sector should be taken into account as a future research. Although the risk estimation tool and the integrated facility planning model are developed as the approaches which can generally be used in any industrial sector, there could be limitations in their application. As an example, applying the integrated facility planning model to different types of plant layout (product, process, fixed-position, and group technology layout) may require changes in some steps of the model.

CONCLUSION AND RECOMMENDATIONS

The importance of safety has grown and there is an urgent need for implementation of safety knowledge in layout design and decision-making as well as in locating departments and machines equipment in production systems. Facility designers can strongly influence a facility's safety by integrating safety considerations into the design process. Although their potential influence on safety has been recognized, designers typically lack knowledge of and limit their involvement in workers' safety. The earlier that the design can be evaluated and any necessary changes made in regards to different safety aspects, the lower the cost of any potential changes to the system.

This research effort involved the accumulation of suggestions for improving workers' safety while in the design phase. This dissertation presented original approaches for estimating risk and integrating OHS aspects in facility layout design, which lead to the a safer working environment for workers and productivity and operational efficiency. The main objective was to develop a simple and practical model for facility planners, so that they can consider safety and cost aspects within a similar importance level when designing a layout for a facility. In order to present such a model, developing a risk estimation tool was required. The proposed risk estimation tool is comprehensive enough to evaluate the risk for every OHS issue. This has been assured by including six risk parameters and five levels for each parameter. Moreover, this tool has the ability of calculating the risk value quantitatively; hence, providing the possibility of integrating it to facility planning models.

The proposed risk estimation tool is further integrated to the traditional facility planning model which is comparable with the SLP model. The integrated OHS facility planning model features both cost and safety objectives when generating a new layout design. Therefore, safety would be considered as important as other factors such as cost or space constraints. It is worth mentioning that the improvements offered by the proposed integrated model are not limited to designing a new facility layout and it can be applied to the current layout of an existing facility to ensure safety improvements.

The proposed model is implemented through a case study at a kitchen of a hospital. The study has aimed to designate a new layout for the kitchen while making it a safer working environment for the personnel. The integrated OHS facility planning model is considered general enough to be applicable in any industrial context. Although, small to medium-sized industries are suggested due to demanding more than one facility planner for decision making as well as the time requirements in executing the model.

The proposed approaches in this dissertation do not only represent efficient tools to deal with estimating risk of different OHS concerns and reducing their effects by considering safety aspects in designing the layout of a facility. They also provide practical tools for facility planners and safety evaluators.

This research opens up a new frontier in the use of facility planning models to better designate the OHS aspects in a facility layout and redesign it to be a safer working environment; hence, saving lives.

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APPENDIX A – Assessing Occupational Health and Safety in Facility Planning: A Case Study

Abstract[5]

Facility planning considers the design, layout, location and accommodation of people, machines and activities of a system or enterprise within a physical environment. Appropriate decisions on facility layout, concerning the spatial allocation of departments and equipment (e.g. machines) and the required connections among them, can organize the production more efficiently and increase safety. A well-designed facility can ensure that adequate space is assigned for maintenance and operation that unnecessary movements are avoided, and the range of machine movement is considered. In spite of this, safety is not considered extensively in facility planning. Occupational Safety and Health Administration (OSHA) has provided little guidance to assist industries in finding reasonable solutions to the issues raised from safety in the layout design.

In this paper, a case study is carried out to investigate the safety issues in relation to layout design. The case study was conducted at a hospital kitchen in Montreal - Canada, which is being fully renovated. The kitchen contains several hazards and numerous equipment. The principles can be easily transposed to a manufacturing context, involving machines.

The case study validates the list of hazards proposed in previous research and adds additional criteria that need to be considered when designing the facility layout for the kitchen. The hazards in the kitchen are presented and will guide the design of the new layout which will consider safety as one of its main factors. In other words, this research improves the layout design by including safety aspects.

A.1 Introduction

[5] Moatari-Kazerouni, A., Chinniah, Y., Agard, B.; (2013); Assessing Occupational Health and Safety in Facility Planning: A Case Study; *Proceeding of Condition Monitoring and Diagnostic Engineering Management (COMADEM2013)*; Helsinki, Finland.

Millions of workers die, are injured or get sick every year as a result of workspace hazards. It is estimated that at least 250 million occupational accidents occur every year worldwide (Alli, 2001). The suffering in terms of human life from these accidents is enormous, while the economic cost of the failure to ensure occupational health and safety (OHS) is also excessive.

Selecting a good facility layout, which is defined as the physical arrangement and assignment of departments and machines to specific locations on the floor, is a critical decision in facility planning (Roslin et al., 2008).

One of the most influential factors affecting the efficiency of a production facility is its layout. A poor layout implies that, regardless of other factors, the facility will be inefficient. The interactions between each pair of departments must be taken into account in order to obtain the most efficient layout. These interactions are the flow of material between departments (Abdinnour-Helm and Hadley, 2000). A measure for efficiency can be based on the total cost of transporting these materials between different departments.

In practice many more factors need to be considered in addition to minimizing the cost involved in movement between departments (Heragu, 2006). As such, one factor is providing a safe environment for personnel.

Unlimited number of hazards can be found in almost any workplace. There are obvious unsafe working conditions, such as unguarded machinery, slippery floors or inadequate fire precautions. There are also a number of categories of insidious hazards, including chemical and physical hazards, psychological hazards, and hazards associated with the non-application of ergonomic principles. When developing a facility layout, designers should consider these hazards.

Furthermore, much attention are being paid to occupational health and safety systems, legal requirements, OHS have become essential, in recent years. A checklist which has been proven to be an efficient tool for safety and risk assessment is expected to bring a company's voluntary initiative into all areas of workplace and facility OHS promotion (Nishikido et al., 2006). On the other hand, most previous checklists have focused mainly on improving ergonomic work conditions or the workplace environment (Harms-Ringdahl, 2001). Some of the literature on applying checklists as a risk assessment tool is presented in following paragraphs.

Nishikido et al. (2006) developed a new multi-dimensional action checklist that can support employers and workers in understanding a wide range of OHS activities and to promote participation in OHS in small and medium-sized enterprises. Their checklist was formulated consisting of 6 core areas, 9 technical areas, and 61 essential items.

Keyserling et al. (1993) developed a two-page checklist for determining the presence of ergonomic risk factors associated with the development of upper extremity cumulative trauma disorders. This checklist was used by plant personnel at four work sites to assess the presence of risk factors in 335 manufacturing and warehouse jobs.

Brodie and Wells (1996) presented a preliminary testing of the reliability and accuracy of three previously developed ergonomics checklists: Rapid Upper Limb Assessment; Occupational Safety and Health Administration draft risk factor checklist; and the Posture and Upper Extremity checklists. The evaluation was carried out in a car manufacturing environment.

Shikdar and Sawaqed (2003) identified factors that affected worker productivity and OHS in selected industries in a developing country and among fifty production managers. Kazutaka (2002) reviewed the research implications of the new principles of occupational safety and health management systems based on recent developments in Asian countries.

Furthermore, the relationship between facilities layout and occupational safety has not been researched extensively. Chang and Liang (2009) developed a model, based on a three level multi-attribute value model approach, in order to evaluate the performance of process safety management systems of paint manufacturing facilities. Fernandez-Muniz et al. (2007) developed a Safety Measurement System Scale, based on the results of a questionnaire survey of 455 Spanish companies, in order to guide the safety activities of organizations.

The objective of this study is to test the checklist, presented by the same authors in a previous study (Moatari-Kazerouni et al., 2012). The same approach presented in that study is used in this paper, which is identifying the risk factors that exist in the facility by going through the items presented in the checklist. Moreover, the safety factors relevant to the layout design of facilities are modified based on a case study implementation. This modified checklist can support facility planners in understanding the value of inclusive array of OHS concerns in facility layout design.

A.2 Methodology and Information Collection

A case study approach is used in this research in order to assess the OHS in the layout re-design of a hospital kitchen in Montreal – Canada.

This research uses the safety criteria checklist for facility layout planning, introduced in Moatari-Kazerouni et al. (2012). The checklist is used to identify the occupational health and safety issues that are not well-considered in the current design of the kitchen, though essential for its new layout.

The information in relation to the hazardous situations that exist in the current design of the kitchen is gathered via observations and interviewing with the kitchen staff.

Several observation sessions as well as performing them in various working hours of the kitchen have insured the validity of collected information. The items indicated in the checklist were evaluated through these observations and field notes were taken.

Moreover, interviewing with the staff shed light on other safety concerns that exist in the kitchen.

A.3 Case Study Description

The case study was conducted in the kitchen of a hospital where the food is prepared, stored and distributed to every patient.

The kitchen was originally design in 1907. Over the time, different improvements and modifications were executed although with no global coordination.

Recently, it was decided to renovate the kitchen by changing the facility layout. The main reason for this renovation is the kitchen being old as well as to enhance additional services such as the room service for having specific food requested at different times than the usual food serving meals. The new concept of room service requires important improvements in the distribution and production area. Different equipment had to be renewed and the facility layout had to be modified to cater for the new concept. Therefore, changes in the layout design of the kitchen seemed necessary and the hospital has decided to update all the food service area.

Since occupational health and safety is one of the important issues to be considered at the hospitals and specifically in the kitchen, this research provided an evaluation of OHS considerations. This case study aimed to investigate the OHS issues regarding every sections and machines in the kitchen.

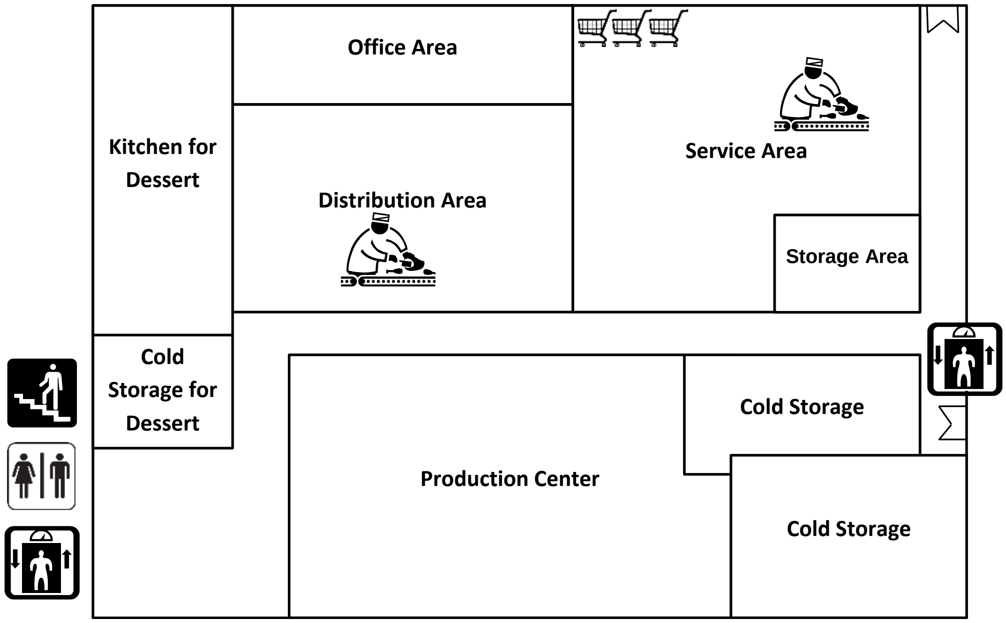

Figure A-1: Current layout of the kitchen

A sketch of the current layout of kitchen is illustrated in Figure A-1. The kitchen consists of different sections: office area, production area (food preparation), distribution centre including a conveyor and workstations for mounting the food trays for patients, service area for weighing portions and selecting ingredients for recipes, section for pastries, area for washing the trolleys (used for transporting trays), area for dismounting the used trays collected from patients, area for washing the dishes and trays, storage areas i.e. refrigerated rooms for perishables and storage room with racks for non-perishables items.

The workers are not presently trained on safety subjects. No particular training or certification program is offered to the staff working in the kitchen. Few guidelines or safety standards are followed by the kitchen; whereas little safety inspections are carried out. Thus, assessing OHS of the current kitchen design is useful before planning its new layout.

A.4 Results and Interpretations

The following sections present the initial safety criteria checklist as well as its case study implementation.

A.4.1 Safety Criteria Checklist

The safety criteria checklist developed by Moatari-Kazerouni et al. (2012) is used in this research. This checklist consists of six major criteria:

Machine safety: this safety factor deals with some of the principals involved in providing safety in oppose to the common hazards caused by machineries and equipment; examples are: placement and distance of machines, machine standardization, storage, safeguards, and material feeding.

Movement: discussions on safety of material handling from the perspective such as load, equipment, gang-way spaces, interruption and unnecessary movements are presented in this safety factor.

Material safety: the type and physical-chemical characteristics of the material used in the manufacturing process are studied in this safety factor.

Workforce and ergonomics: safety of workers is ensured by exercising factors including: their experience, training and education, flexibility of jobs, Contact between workforce and machines, use of personal protective equipment, as well as the ergonomics approaches.

Maintenance and service: accessibility and distances among machines, as well as the maintenance services concerned this safety factor.

Environmental safety: the working environment should provide proper illumination, noise control, ventilation and temperature in order to accommodate the workers. Other environmental hazards could be caused from electricity and released of stored energy, fire and thermal changes, and waste disposal.

The elements of these six safety criteria are used to assess the OHS in the current design of the kitchen.

A.4.2 OHS Assessment in the Hospital Kitchen

The following paragraphs discuss on studying the safety criteria checklist by means of observations and interviews. The applicable OHS issues are briefly described.

A.4.2.1 Machine Safety Criteria

Placement of machines

- Each machine has its own power supply and energy isolating devices.
- There is one dish washing machine/conveyor in the kitchen. This cause long queue of trolleys filled with dirty dishes waiting for getting washed.

Standardization of machines

- Use of machines is restricted to the authorized personnel (who can receive little training).
- Proper and safe utilisation of tools according to the manufacturer's instructions is used. The labels and guidance are attached on the machines and equipment about how to use them. Instructions about the buttons and valves of the machines are available; e.g., warning signs or safety precautions for using ovens are available on the machine.

Storage space

- Storage locations for each type of item are planned separately. Liquid and solid materials are kept well separated. Storage spaces for cold and raw material are separate. Products are shelved based on their characteristics (e.g., meat, dairy, vegetables) in the storage refrigerators.
- Incompatible materials are separated. Chemical liquids are stored in a place different from other material while properly labelled.
- Each storage area can contain a certain quantity of material.
- Materials are kept organized in the storage areas. The materials are kept within their boxes or the racks when they are placed on the shelves. Similarly, inside the cold storage area, materials are kept within the trolleys.
- Specific labels are used for the material kept in the storage. Storage drawers as well as all the cabinets are labelled based on their content.
- There seems to be no rule that asks to keep the lighter material on top and heavier material on the lower shelves in the raw material storage area.
- The distance of the material on the top shelf from the ceiling is adequate.
- Storage piles are stable and secured from falling or collapse.

Machine safeguard flexibility

- The vegetable slicer is not properly safeguarded.
- The person working with the meat slicer does not consider every safety issues by just putting his hand on the edge of the cutter.

A.4.2.2 Movement Safety Criteria

Material handling load

- The loads are properly balanced and secured.
- Workers do not always follow the weight limits for manual lifting, carrying, pushing and pulling. For example, a worker was observed pushing several trolleys at the same time.

Material handling method and equipment

- Manual handling aids are accessible. The wheeled stool is used to carry vessels between machines (e.g., for moving the hot and boiling pots to the oven or the mixer machine). Also ladders are available to reach the material on higher shelves at the storage area.
- Trolleys are numbered and placed in their specific location in the service area.
- Trolleys are sometimes used to carry both cold and warm food. This can cause problem when loading the trailer with for example cold food right after it has been unloaded from the warm food (while tray is still warm).
- Proper lifting techniques are considered; e.g., trolleys are used to move the material, food, and dishes.

Minimum aisle widths

- Sufficient gang-way space for materials is considered; e.g., enough corridor and aisle between the rows at the storage area.
- Sufficient space for the operators around the machines as well as sufficient aisle for the material handling equipment is considered.

More/longer distance unnecessary movements are not always avoided. For instance, the raw materials as well as the dirty dishes are brought back to the kitchen by using the elevator which is located on the side of the kitchen and on opposite to the raw storage and the dish washing conveyor.

Un-safe interruption in material handling may not be avoided. The corridors used for the workers are the same as the ones used for the material handling equipment. This causes interruption in movements as workers may bump into the material handling equipment while it is also dangerous, for example when hot pots are carried.

A.4.2.3 Material Safety Criteria

Type of product (physical-chemical characteristics): all materials and their containers are labelled.

Information and guidelines about WHMIS (Workplace Hazardous Materials Information System) is posted on the wall.

A.4.2.4 Workforce & Ergonomics Safety Criteria

Training and education

- Workers are not trained and tested on safety subjects. No particular training or certification program is offered to the staff.
- Workers are experienced.
- Only authorized personnel can enter the kitchen.
- Only authorized personnel work with the machines.

Personal protective equipment

- Approved protective equipment is available; e.g. gloves, special hats, lab coat and apron.
- Protective equipment is used against hazards that cannot be eliminated. The use of special hats and the white lab coats are mandatory. However, wearing cloves is not an obligation in the kitchen.
- Protective equipment, emergency and first aid equipment are easily accessible. They are stored as close as practicable to the point of use and their locations are clearly marked.
- The protective equipment is located right before entering the kitchen, therefore easily recognizable and accessible by the staff.

Job flexibility

- Confusions caused from several operations which carried out simultaneously are avoided.
- A work can have flexible schedule with variable start/end.

Contact between workforce and machines

- Stable work platform suitable for the nature of the work exists. Every machine is grounded and stabilised on its position.
- There is safe access to the machine for operators from every possible corner.

Ergonomic hazards

- Using physical force (lifting heavy objects) is avoided by using trolleys for different movements; e.g., transferring food to the rooms, food/material to the refrigerators and storage spaces, as well as for dishes.
- Duration of the job being over a long period is not an issue in the kitchen.

A.4.2.5 Environmental Safety Criteria

Lack of illumination

- Illumination is adequate for the normal conditions at the kitchen. However, some of the lights, especially in the distribution area, are not working properly or are out of work.
- The exit lights are properly illuminated.

Noise disturbance

Noise levels are within acceptable limits in the kitchen. However, the dish washing conveyor can be noisy and disturbing for the operators around it. Also the noise caused from the ventilation system can be annoying.

Respiratory hazards

- The ventilation system is employed in the kitchen to control the respiratory hazards. However, it does not work properly. Its flow rate and fan speed are not adequate and the noise level is high. This can be because of the ventilation filter being greasy and smoky since it has not been changed for a long time. Consequently, for example, the steam from the cooking is not absorbed well.

- Improper ventilation by using fans instead of the air conditioning; while fans are placed in front of each other which will not allow the circulation of air.
- Special funnel are used to direct the vapour produced from the dish washing machine to the outside.

Sewage and waste disposal

- There are special paths under the boiling containers for the waste water and liquids. However, some floors of the kitchen are slippery because of the waste water (e.g. floating water near the dish washing machine).
- The elevators used for transporting the sewage and disposals are different from the ones used for delivering food and kitchen material.
- Waste storage areas, e.g. bins and containers, are available. They are kept closed except when adding waste.

Fire and explosion

- Portable fire extinguishers are mounted properly, accessible and inspected. There are signs indicating the location of the fire extinguisher.
- "No Smoking" areas are designated and signs clearly indicate it.
- Smoke and heat detectors are available and functional in every area of the kitchen. Fire alarms are installed in place.
- The guidelines in case of fire (e.g. fire from the oven) are available.

Electricity or released of stored energy

- Cables, plugs and insulation are damaged in some places.
- Machinery and equipment are grounded.
- Electrical panels have clear access and are clearly marked.
- Outlets, switches and boxes have covers.
- There is the permanent wiring in place; no extension cords are used while separate sockets are used to plug in for different machines.

- Emergency stops and critical controls are identified. The emergency stop button is used for the food conveyer, washing machine conveyor, etc.
- Electric boxes are locked, the sign of danger is placed on the box, instructions and warnings are also available on the box.
- Instruction about the voltage that should be used for the machines are available on them.

Emergency and life safety

- Emergency exits are clearly identified and exit signs are available.
- Entry/exit doors are designed in different sides of the kitchen.
- Walkways maintained, aisles defined and uncluttered. Aisles are defined and their limits are marked with yellow-black colours.
- Aisle ways are not free from material storage and debris in every place. There are some boxes and cartons placed unattended.
- There are devices to detect, warn and protect against an impending/existing adverse environmental condition; e.g. speakers are placed in different locations of the kitchen.
- First aid kits are available.

Thermal Changes

- The dish washing machine cause a lot of heat in place and the fans cannot cool down the environment.
- Guidelines about the necessary temperature are available.

Hygiene

- Guidelines and information notes about the hygiene are available (e.g. for cleaning).
- Guidelines and notes about using the material and products (e.g. to always check out the expiration date of products before using them) are available.
- Guidelines for using the products for hand washing and for washing the dishes are available.
- Plan of the hygiene of the kitchen is placed on the wall.

- Hand washing sinks are available in different locations of the kitchen.
- Housekeeping and cleaning tools/material are available.
- Fly-traps are hung from the ceiling in different locations.
- The special hats and lab coats should be worn when being inside the kitchen and special signs indicate its necessity.
- Using gloves is not very common among the employees but also not an obligation at the kitchen.

A.4.2.6 Infrastructure

Corrosion and cracks

- Corrosion and rusting exist on some of the pipes.
- There exist cracks on the walls and behind the machines.
- Cracks and corrosions exist at the vapour funnel of the dish washing machine.

Facilities locations

- The height of the ceiling in the two sections of the kitchen (distribution and production areas) is different, while the height of the ceiling in some places seems to be inadequate. It can cause problem for example in some storage areas.
- The office areas are well separated from the kitchen and the storage areas.
- The washrooms are located in a separate place from the other parts of the kitchen.
- Plan of the kitchen areas and the machines that are in the kitchen is placed on the wall.
- Different elevators are used for the food, one for the dirty dishes and one for the waste and disposal material.
- There are specific schedules for using the elevators.
- A specific location is assigned to the dirty cloths and gloves.

A.5 Further Discussion

For this particular case application, the “maintenance and service” safety factor of the checklist was not relevant. The new safety factor of “infrastructure” was discussed. Whereas other safety issues, for example life safety and hygiene, were proposed for being included in the checklist. Therefore, the safety criteria checklist could be modified as presented in Table A.1.

The study signified that the “environmental” issues bring up the main safety concerns in the hospital kitchen. The ventilation system requires major repair since it does not work properly. Parts of the lighting system, especially in the distribution area, do not function; therefore need to be changed. Besides, more strict regulations have to be employed for wearing gloves in the kitchen.

Un-safe interruptions in material handling are another safety concern in the kitchen. The absence of a predefined direction for workers and material handling equipment movements lead to this problem, which could be resolved by a better layout design. Similarly, unnecessary movements in the longer distances could be avoided by considering changes in the layout design.

Corrosion and rusting as well as the cracks on the walls require significant consideration. Additionally, the possibility of equalling the height level of the ceiling in the distribution and production areas should be deemed.

Changing the dish washing conveyor to one which can handle more plates could solve the problem of the long queue of dirty dishes’ trolleys. However, the cost factor consequences have to be taken into consideration. Otherwise, not connecting the dirty dishes as they are being removed from the trolleys to the dish washing conveyor could be an option.

Furthermore, workers should be given adequate training and be evaluated on the safety subjects. Also the vegetable slicer and meat slicer machines have to be properly safeguarded.

These safety factors need to be considered more precisely in order to be modified for the new design of the kitchen layout. However, in applying the facility planning tools for designing the new layout, not all these factor is already deliberated (e.g. the environmental safety factors). Numerous problems can be avoided in designing or modifying layouts if facilities plans are reviewed for safety aspects before initiating any construction or change. Hence, developing a model which integrates safety factors in facility planning tools is necessary. By this means, safety issues would be considered as an important factor as cost, closeness, material flow, flexibility, or material handling system concerns, in the facility layout problems.

Table A.1: Modified safety criteria checklist

Machine	- Placement and distance of machines - Standardization of machines - Degree of automation - Storage space - Machine safe guards flexibility ***** - Safety in material feeding *****
Movement	- Material handling load - Material handling method and equipment - Machine movement - Minimum aisle widths - Safe guarding the material handling equipment ***** - More/longer distance unnecessary movements ***** - Un-safe interruption in material handling *****
Workforce & Ergonomics	- Training and education - Personal protective equipment ***** - Job flexibility - Contact between workforce and machines - Ergonomic hazards
Maintenance & Service	- Access to machines for setting, maintenance or repair - Machine safe guard flexibility - Adequate space for critical maintenance and auxiliary services during operation *****
Material	- Type of product (physical-chemical characteristics) ***** - Characteristics of product (e.g. size, shape, volume, weight) - Material safety information and guidelines *****
Environmental	- Lack of illumination - Noise disturbance - Respiratory hazards - Sewage and waste disposal ***** - Fire and explosion - Compressed air and gases ***** - Electricity or released of stored energy - Emergency and life safety ***** - Thermal changes - Radiation hazards ***** - Hygiene *****
Infrastructure *	- Corrosion and cracks ***** - Facilities locations *****

***** *Newly added safety criteria*

A.7 Conclusions

Improving worker productivity and occupational health and safety are major concerns of industries. One of the common features of these industries is the improper facility design. This leads to workplace hazards, poor worker health, mechanical equipment injuries and disabilities, which, in turn, would reduce workers' productivity, the work quality and increases the cost. This has effects on the overall performance of a company. It would, therefore, be extremely difficult to attain company objectives without giving proper consideration to OHS concerns when planning the facility layout.

The main objective of this research was to appraise a list of safety criteria which was developed to be considered when planning the initial design or modifications in layout of facilities. Different issues suggested in this list were evaluated and the ones that needed to be considered more precisely were identified in order to be adapted in the new design of the kitchen layout. Hence, the research has validated the list of safety criteria proposed in Moatari-Kazerouni et al. (2012), while investigated its actual implementation through a case study at a hospital kitchen.

The outcomes of this research provide a tool that can help providing a safer working environment for the kitchen staff and which can be applied to other layouts; it identified the various risks in the kitchen and guides the proposal of OHS changes that need to be considered when redesigning the kitchen layout.

APPENDIX B – The 20 Hazardous Scenarios

Scenario Number - Hazard Type	Activity	Hazard	Hazardous Situation
A-mechanical hazard	Functional demonstration of a punching machine during a commercial show/expo. The punching machine is in automatic mode	Lateral movement of the table holding sheet metal to be punched	A person is located near the moving table
B-mechanical hazard caused by electrical fault	Tool (whisk) change on a food mixer	Rotary movement of the whisk	The worker is in contact with the whisk
C-radiation hazard	Luggage inspection	Electromagnetic radiation (X-rays)	The worker functions within a 5 meter parameter of the X-ray machine.
D-ergonomic hazard	Loading a new roll of polythene netting on a hay baling machine.	Posture, constructing position, dangerous access (steps/platform)	The workers have to manually handle a roll of polythene weighting approximately 25 kg and load in upper part of machine indicated by arrow. Steps are provided but not suitable considering person in balancing heavy and awkward load. They therefore just get in the way.
E-materials/substances hazard	Lubricating a moving chain with the guards removed	Toxic material (oils)	Worker is situated close to the oil and moving parts

Scenario Number - Hazard Type (continue)	Activity (continue)	Hazard (continue)	Hazardous Situation (continue)
F-material substance hazard	Sanding panels within a body shop.	Dust inhalation.	The dust accumulation is apparent within the immediate vicinity of the worker.
G-mechanical hazard	A self-guided vehicle moves through a workshop	Movement of the self-guided vehicle	Self-guided vehicle operates in same area where several employees walk
H-ergonomic hazard	The workers are threading paper into the feed rollers	Poor posture, constrained	The workers are leant forward in an unstable and uncomfortable position
I-pressure hazard	De-icing an airplane prior to take off in sub-zero weather conditions.	Pressurised water/glycol solution (approx. 40 bar) at high temperature (150-180^{o}F)	The activity requires the worker to manually handle the high pressure hose.
J-noise hazard	Operating large panel press.	Ambient noise is above 85 dB.	Workers are in the vicinity.
K- slips, trips and falls hazard	Repair of conveyor drive mechanism. The conveyor is stopped.	Electricity	Proximity to live parts
L-mechanical hazard	Inspection and maintenance of the pulley drive mechanism	Movement of the drive pulley of the belt - being drawn-into in-running nip.	Being in contact with the belt and pulley near a drawing-in point.
M-mechanical hazard	Removing the torn/damaged parts from rollers in pulp and paper industry . The reel is in manual mode	Drawing in by large roller.	The hands of the two workers are near the drawing-in point.
N- thermal hazard	Working on a conveyor for carrying food	Presence of molten metal and sparks	Welding in the proximity of sawdust

Scenario Number - Hazard Type (continue)	**Activity (continue)**	**Hazard (continue)**	**Hazardous Situation (continue)**
O-slips, trips and falls hazard	Releasing a trapped log from a conveyor. The worker is situated on the conveyor 3 m above the ground.	Bad stability – gravitational force	Working at height
P-vibration hazard	Cutting car body panels using a pneumatic reciprocating saw.	Hand-arm vibration (HAV) from the saw.	Prolonged exposure to vibration generated by reciprocating saw.
Q-mechanical hazard	Operation of circular saw to cut large and unusual shapes.	Spinning saw blade	Operator hands in vicinity of blade when removing the work piece.
R-thermal hazard	Cutting out thermo-formed panel	Elevated temperature of cut panel (60^{o}C)	Worker in the proximity of the panel
S-mechanical hazard	Tooling change on a robot fed CNC lathe	Movement of the robot	The worker is situated in the trajectory of the robot. Robot is currently in Home position and still energised
T-material substance hazard	Cooling of plastic extrusions	Legionella bacteria	Warm water recycled from sump, debris and dust are able accumulate within cooling water.